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ALTITUDE DEVELOPMENTAL TESTING OF THE J-2S ROCKET ENGINE IN PROPULSION ENGINE TEST CELL (J-4) (TESTS J4-1902-09 AND J4-1902-10)

M. R. Collier and C. E. Pillow
ARO, Inc.

November 1969

Per A.F. letter dtd 12 July 74 signed William O. Co

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ALTITUDE DEVELOPMENTAL TESTING OF THE J-2S ROCKET ENGINE IN PROPULSION ENGINE TEST CELL (J-4) (TESTS J4-1902-09 AND J4-1902-10)

M. R. Collier and C. E. Pillow

ARO, Inc.

FOREWORD

The work reported herein was sponsored by the National Aeronautics and Space Administration (NASA), Marshall Space Flight Center (MSFC) (PM-EP-J), under Program Area 921E, Project 9194.

The results of the tests presented were obtained by ARO, Inc., (a subsidiary of Sverdrup & Parcel and Associates, Inc.), contract operator of the Arnold Engineering Development Center (AEDC), Air Force Systems Command (AFSC), Arnold Air Force Station, Tennessee, under Contract F40600-69-C-0001. Program direction was provided by NASA/MSFC; technical and engineering liaison was provided by North American Rockwell Corporation, Rocketdyne Division, manufacturer of the J-2S rocket engine, and McDonnell Douglas Astronautics Company, manufacturer of the S-IVB stage. The testing reported herein was conducted on April 17 and 24, 1969, in Propulsion Engine Test Cell (J-4) of the Large Rocket Facility (LRF) under ARO Project No. KA1902. The manuscript was submitted for publication on August 25, 1969.

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This technical report has been reviewed and is approved.

Edgar D. Smith
Major, USAF
AF Representative, LRF
Directorate of Test

Roy R. Croy, Jr.
Colonel, USAF
Director of Test

ABSTRACT

Five idle-mode firings of the Rocketdyne J-2S rocket engine (S/N J-112-1A) were conducted in Test Cell J-4 of the Large Rocket Facility on April 17 and 24, 1969. These firings were accomplished during test periods J4-1902-09 and J4-1902-10 at pressure altitudes of approximately 100,000 ft at engine start. The objectives were: (1) to investigate engine idle-mode operating characteristics with a redesigned injector (oxidizer idle-mode compartment consisted of the injector posts in the tenth row from the center of the injector), (2) to determine fuel injection density for varying pump inlet pressures, and (3) to determine engine idle-mode performance. The lowest injection density was 0.055 lb_m/ft^3 with the thrust chamber bypass valve closed. Engine average characteristic velocity for this injector configuration was about 2.6 percent greater than that recorded during tests with the previous injector.

CONTENTS

APPENDIXES

I. ILLUSTRATIONS

NOMENCLATURE

A	Area, in.^{2}
ASI	Augmented spark igniter
C*	Characteristic velocity, ft/sec
CCP	Customer connect panel
EBW	Exploding bridge wire
FM	Frequency modulation
MFV	Main fuel valve
MOV	Main oxidizer valve
O/F	Propellant mixture ratio, oxidizer to fuel, by weight
SPTS	Solid-propellant turbine starter
T/C	Thrust chamber
t_0	Time at which helium control and idle-mode solenoids are energized; engine start
VSC	Vibration safety counts, defined as engine vibration in excess of 50 g rms in a 960- to 6000-Hz frequency range

SUBSCRIPTS

f	Force
m	Mass
t	Throat

SECTION I
INTRODUCTION

Testing of the Rocketdyne J-2S rocket engine using an S-IVB battleship stage has been in progress since December, 1968, at AEDC. The five firings reported herein were conducted during test periods J4-1902-09 and J4-1902-10 in Propulsion Engine Test Cell (J-4) (Figs. 1 and 2, Appendix I) of the Large Rocket Facility (LRF). These firings were to investigate engine idle-mode operating characteristics with a redesigned oxidizer idle-mode compartmented injector, to determine fuel injector density for various pump inlet pressures, and to determine engine idle-mode performance with the redesigned injector. The firings were accomplished at pressure altitudes ranging from 74,000 to 103,000 ft (geometric pressure altitude, Z, Ref. 1) at engine start. Data collected to accomplish the test objectives are presented herein. The results of earlier testing of the previous injector design are presented in Ref. 2.

SECTION II
APPARATUS

2.1 TEST ARTICLE

The test article was a J-2S rocket engine (Fig. 3) designed and developed by Rocketdyne Division of North American Rockwell Corporation. The engine uses liquid oxygen and liquid hydrogen as propellants and is designed to operate either in idle mode at a nominal thrust of 5000 lb_f and mixture ratio of 2.5 or at main stage at any precalibrated thrust level between 230,000 and 265,000 lb_f at a mixture ratio of 5.5. The engine design is capable of transition from idle-mode to main-stage operation after a minimum of 1-sec idle mode; from main stage the engine can either be shut down or make a transition back to idle-mode operation before shutdown. An S-IVB battleship stage was used to supply propellants to the engine. A schematic of the battleship stage is presented in Fig. 4.

Listings of major engine components and engine orifices for this test period are presented in Tables I and II, respectively (Appendix II). All engine modifications and component replacements performed during this report period are presented in Tables III and IV, respectively.

2.1.1 J-2S Rocket Engine

The J-2S rocket engine (Figs. 3 and 5 and Ref. 3) features the following major components:

1. Thrust Chamber - The tubular-walled, bell-shaped thrust chamber consists of an 18.6-in.-diam combustion chamber with a throat diameter of 12.192 in., a characteristic length (L*) of 35.4 in., and a divergent nozzle with an expansion ratio of 39.62. Thrust chamber length (from the injector flange to the nozzle exit) is 108.6 in. Cooling is accomplished by the circulation of engine fuel flow downward from the fuel manifold through 180 tubes and then upward through 360 tubes to the injector and by film cooling inside the combustion chamber.

2. Thrust Chamber Injector - The injector is a concentric-orificed (concentric fuel orifices around the oxidizer post orifices), porous-faced injector. Fuel and oxidizer injector orifice areas are 19.2 and 5.9 in.^{2}, respectively. There are 614 oxidizer post orifices in the injector. The porous material, forming the injector face, allows approximately 3.5 percent of main-stage fuel flow to transpiration cool the face of the injector. The oxidizer idle-mode compartment consists of a radial line of injector posts connecting the center of the injector with the posts in the tenth row from the center (76 oxidizer post orifices). This injector design is commonly referred to as the "row ten" injector. The oxidizer idle-mode compartment in the previously used injector consisted of the inner four rows of oxidizer injector posts (72 oxidizer post orifices). This injector design is commonly referred to as the "inner 4 rows" injector.

3. Augmented Spark Igniter - The augmented spark igniter unit is mounted on the thrust chamber injector and supplies the initial energy source to ignite propellants in the main combustion chamber. The augmented spark igniter chamber is an integral part of the thrust chamber injector. Fuel and oxidizer are ignited in the combustion area by two spark plugs.

4. Fuel Turbopump - The fuel turbopump is a one and one-half stage, centrifugal-flow unit, powered by a direct-drive, two-stage turbine. The pump is self-lubricated and nominally produces, at the 265,000-lb_f-thrust rated condition, a head rise of 60,300 ft of liquid hydrogen at a flow rate of 9750 gpm for a rotor speed of 29,800 rpm.

5. Oxidizer Turbopump - The oxidizer turbopump is a single-stage, centrifugal-flow unit, powered by a direct-drive, two-stage turbine. The pump is self-lubricated and nominally produces, at the 265,000-lb_f-thrust rated condition, a head rise of 3250 ft of liquid oxygen at a flow rate of 3310 gpm for a rotor speed of 10,500 rpm.

6. Propellant Utilization Valve - The motor-driven propellant utilization valve is a sleeve-type valve which is mounted on the oxidizer turbopump and bypasses liquid oxygen from the discharge to the inlet side of the pump to vary engine mixture ratio.

7. Main Oxidizer Valve - The main oxidizer valve is a pneumatically actuated, two-stage, butterfly-type valve located in the oxidizer high pressure duct between the turbopump and the injector. The first-stage actuator positions the main oxidizer valve at the 12-deg position to obtain initial main-stage-phase operation; the second-stage actuator ramps the main oxidizer valve full open to accelerate the engine to the main-stage operating level.

8. Main Fuel Valve - The main fuel valve is a pneumatically actuated butterfly-type valve located in the fuel high-pressure duct between the turbopump and the fuel manifold.

9. Pneumatic Control Package - The pneumatic control package controls all pneumatically operated engine valves and purges.

10. Electrical Control Assembly - The electrical control assembly provides the electrical logic required for proper sequencing of engine components during operation. The logic requires a minimum of 1-sec idle-mode operation before transition to main stage.

11. Flight Instrumentation Package - The instrumentation package contains sensors required to monitor critical engine parameters. The package provides environmental control for the sensors.

12. Helium Tank - The helium tank has a volume of 4000 $in.^3$ and provides a helium pressure supply to the engine pneumatic control system for three complete engine operational cycles.

13. Thrust Chamber Bypass Valve - The thrust chamber bypass valve is a pneumatically operated, normally open, butterfly-type valve which normally allows fuel to bypass the thrust chamber body during idle-mode operation.

14. Idle-Mode Valve - The idle-mode valve is a pneumatically operated ball-type valve which supplies liquid oxygen to the idle-mode compartment of the thrust chamber injector during both idle-mode and main-stage operation.

15. Hot Gas Tapoff Valve - The hot gas tapoff valve is a pneumatically operated butterfly-type valve which provides on-off control of combustion chamber gases to drive the propellant turbopumps.

16. Solid-Propellant Turbine Starter - The solid-propellant turbine starter provides the initial driving energy (transition to main stage) for the propellant turbopumps to prime the propellant feed systems and accelerate the turbopumps to 75 percent of their main-stage operating level. A three-start capability is provided.

2.1.2 S-IVB Battleship Stage

The S-IVB battleship stage, which is mechanically configured to simulate the S-IVB flightweight vehicle, is approximately 22 ft in diameter and 49 ft long and has a maximum usable propellant capacity of 43, 000 lb of liquid hydrogen and 194, 000 lb of liquid oxygen. The propellant tanks, fuel above oxidizer, are separated by a common bulkhead. Propellant prevalves, in the low pressure ducts (external to the tanks) interfacing the stage and engine, retain propellants in the stage until being admitted into the engine to the main propellant valves and serve as emergency engine shutoff valves. Vent and relief valve systems are provided for both propellant tanks.

Pressurization of the fuel and oxidizer tanks was accomplished by facility systems using hydrogen and helium, respectively, as the pressurizing gases. The engine-supplied gaseous hydrogen and gaseous oxygen for fuel and oxidizer tank pressurization during flight were routed to the respective facility venting systems.

2.2 TEST CELL

Propulsion Engine Test Cell J-4, Fig. 2, is a vertically oriented test unit designed for static testing of liquid-propellant rocket engines

and propulsion systems at pressure altitudes of 100, 000 ft. The basic cell construction provides a 1.5-million-lb_f-thrust capacity. The cell consists of four major components (1) test capsule, 48 ft in diameter and 82 ft in height, situated at grade level and containing the test article; (2) spray chamber, 100 ft in diameter and 250 ft in depth, located directly beneath the test capsule to provide exhaust gas cooling and dehumidification; (3) coolant water, steam, nitrogen (gaseous and liquid), hydrogen (gaseous and liquid), and liquid-oxygen and gaseous-helium storage and delivery systems for operation of the cell and test article; and (4) control building, containing test article controls, test cell controls, and data acquisition equipment. Exhaust machinery is connected with the spray chamber and maintains a minimum test cell pressure before and after the engine firing and exhausts the products of combustion from the engine firing. Before a firing, the facility steam ejector, in series with the exhaust machinery, provides a pressure altitude of 100, 000 ft in the test capsule. A detailed description of the test cell is presented in Ref. 4.

The battleship stage and the J-2S engine were oriented vertically downward on the centerline of the diffuser-steam ejector assembly. This assembly consisted of a diffuser duct (20 ft in diameter by 150 ft in length), a centerbody steam ejector within the diffuser duct, a diffuser insert (13.5 ft in diameter by 30 ft in length) at the inlet to the diffuser duct, and a gaseous-nitrogen annular ejector above the diffuser insert. The diffuser insert was provided for dynamic pressure recovery of the engine exhaust gases and to maintain engine ambient pressure altitude (attained by the steam ejector) during the engine firing. The annular ejector was provided to suppress steam recirculation into the test capsule during steam ejector shutdown. The test cell was also equipped with (1) a gaseous-nitrogen purge system for continuously inerting the normal air in-leakage of the cell; (2) a gaseous-nitrogen repressurization system for raising test cell pressure, after engine cutoff, to a level equal to spray chamber pressure and for rapid emergency inerting of the capsule; and (3) a spray chamber liquid-nitrogen supply and distribution manifold for initially inerting the spray chamber and exhaust ducting and for increasing the molecular weight of the hydrogen-rich exhaust products.

2.3 INSTRUMENTATION

Instrumentation systems were provided to measure engine, stage, and facility parameters. The engine instrumentation was comprised of (1) flight instrumentation for the measurement of critical engine parameters and (2) facility instrumentation which was provided to verify the

flight instrumentation and to measure additional engine parameters. The flight instrumentation was provided and calibrated by the engine manufacturer; facility instrumentation was initially calibrated and periodically recalibrated at AEDC. Appendix III contains a list of all measured engine test parameters and the locations of selected sensing points.

Pressure measurements were made using strain-gage and capacitance-type pressure transducers. Temperature measurements were made using resistance temperature transducers and thermocouples. Oxidizer and fuel turbopump shaft speeds were sensed by magnetic pick-up. Fuel and oxidizer flow rates to the engine were measured by turbine-type flowmeters which are an integral part of the engine. The thrust chamber bypass flow was measured by a turbine-type flowmeter which was installed in a specially fabricated bypass duct. Vibrations were measured by accelerometers mounted on the oxidizer injector dome, the thrust chamber throat, and the turbopumps. Primary engine and stage valves were instrumented with linear potentiometers and limit switches.

The data acquisition systems were calibrated by (1) precision electrical shunt resistance substitution for the pressure transducers and resistance temperature transducer units; (2) voltage substitution for the thermocouples; (3) frequency substitution for shaft speeds and flow meters; and (4) frequency-voltage substitution for accelerometers and the capacitance-type pressure transducer.

The types of data acquisition and recording systems used during this test period were (1) a multiple-input digital data acquisition system scanning each parameter at 50 samples per second and recording on magnetic tape; (2) single-input, continuous-recording FM systems recording on magnetic tape; (3) photographically recording galvanometer oscillographs; (4) direct-inking, null-balance, potentiometer-type X-Y plotters and strip charts; and (5) optical data recorders. Applicable systems were calibrated before each test (atmospheric and altitude calibrations). Television cameras, in conjunction with video tape recorders, were used to provide visual coverage during an engine firing, as well as for replay capability for immediate examination of unexpected events.

2.4 CONTROLS

Control of the J-2S engine, battleship stage, and test cell systems during the terminal countdown was provided from the test cell control room. A facility control logic network was provided to interconnect

the engine control system, major stage systems, the engine safety cut-off system, the observer cutoff circuits, and the countdown sequencer. A schematic of the engine start control logic is presented in Fig. 6. The sequence of engine events for start and shutdown is presented in Figs. 7a and b.

SECTION III
PROCEDURE

Preoperational procedures were begun several hours before the test period. All consumable storage systems were replenished, and engine inspections, leak checks, and drying procedures were conducted. Propellant tank pressurants and engine pneumatic and purge gas samples were taken to ensure that specification requirements were met. Chemical analysis of propellants was provided by the propellant suppliers. Facility sequence, engine sequence, and engine abort checks were conducted within a 24-hr time period before an engine firing to verify the proper sequence of events. Facility and engine sequence checks consisted of verifying the timing of valves and events to be within specified limits; the abort checks consisted of electrically simulating engine malfunctions to verify the occurrence of an automatic engine cutoff signal. A final engine sequence check was conducted immediately preceding the test period.

Oxidizer injector and thrust chamber jacket purges were initiated before evacuating the test cell. After completion of instrumentation calibrations at atmospheric conditions, the test cell was evacuated to approximately 0.5 psia with the exhaust machinery, and instrumentation calibrations at altitude conditions were conducted. Immediately before loading propellants on board the vehicle, the cell and exhaust-ducting atmosphere was inerted. At this same time, the cell nitrogen purge was initiated for the duration of the test period. The vehicle propellant tanks were then loaded, and the remainder of the terminal countdown was conducted. Table V presents the engine purges during the terminal countdown and immediately following the engine firing.

SECTION IV
RESULTS AND DISCUSSION

4.1 GENERAL

Five idle-mode firings of the Rocketdyne J-2S rocket engine (S/N J-112-1A) were accomplished during test periods J4-1902-09 and

J4-1902-10 on April 17 and 24, 1969, respectively. Pressure altitude at engine start ranged from 74,000 to 103,000 ft.

The objectives of the two tests reported herein were to determine idle-mode performance and fuel injection density with the redesigned injector which utilized the tenth row only oxidizer injection during idle mode. A secondary objective of all firings was to determine thrust chamber chilldown rates. The following matrix provides significant test to test variables and corresponding results.

		Pump Inlet Pressures		Flow Rates						Inner 4 Rows Injector Performance			
Firing	Duration, sec	Oxidizer, psia	Fuel, psia	Total Oxidizer, lb_m/sec	Total Fuel, lb_m/sec	T/C Fuel Bypass Flow, lb_m/sec	O/F	Fuel Injection Density, lb_m/ft^3	C*, ft/sec	O/F	Fuel Injection Density,	C*	Test
09A	76.3	38.7	33.0	15.3	8.80	5.19	1.74	0.145	3056	---	---	---	---
09B	75.8	44.8	30.0	16.6	9.55	6.45	1.74	0.286	2464	---	---	---	---
10A	125.1	38.8	32.9	15.1	5.29	0	2.86	0.055	2955	1.71	0.31	2880	07A
10B	100.7	44.6	30.1	16.4	7.30	3.89	2.24	0.108	2814	---	---	---	---
10C	60.6	30.0	40.4	11.8	11.1	4.63	1.07	0.262	2954	---	---	---	---

Generally, the performance of the row 10 injector was comparable to that of the inner 4 row injector. For the single instance where direct comparison is possible, the table shows performance of the row 10 was only slightly improved over the inner 4 rows (2.6 percent for C*) as opposed to the desired 20- to 30-percent improvement. The row 10 injector does not therefore provide a significant improvement in either performance or density relative to that desired or comparable to sea-level test results.

The results of each firing are presented in subsequent sections. The data presented were obtained using the digital data acquisition system, except where indicated otherwise. The accumulated idle-mode firing duration for these firings was 438.5 sec.

Test requirements and specific test results are summarized in Table VI. Start and shutdown transient operating times for selected engine valves are presented in Table VII. Engine idle-mode performance, as calculated in Appendix IV, is presented in Table VIII. Engine start conditions for propellant pump inlets and helium tank are shown in Fig. 8. Figures 9 through 33 present the results of the firings.

4.2 TEST RESULTS

4.2.1 Firing J4-1902-09A

Firing 09A was a 76.3-sec duration idle-mode firing. Characteristic velocity at steady-state conditions was 3050 ft/sec. Calculated fuel

injection density was 0.173 lb_m/ft^3 at this time (see Appendix IV). Saturated conditions (two phase) at the injector were attained at t_0 + 20 sec. These results are comparable to those obtained with the inner 4 rows injector reported in Ref. 2.

The thrust chamber chilldown rate was affected beginning at approximately t_0 + 17 sec by an increase in test cell ambient pressure and temperature. Data beyond this point are not considered representative of normal idle-mode steady-state operation since fuel injection density was lower on 09A than on 10A even though 09A utilized a greater bypass flow rate. High cell pressure (7.05 psia) and warm gases recirculating in the test cell produced significant heat transfer to the thrust chamber. Transient side loads measured were less than ±500 lb_f.

4.2.2 Firing J4-1902-09B

Firing 09B was conducted for 75.8 sec of idle mode. The fuel at the injector became saturated (two phase) at t_0 + 55 sec. Calculated fuel injection density was 0.286 lb_m/ft^3 at t_0 + 74.5 sec. The characteristic velocity at this time was 2464 ft/sec. These results are also comparable to those obtained with the inner 4 rows injector of Ref. 2.

Test cell pressure and temperature were increasing gradually until t_0 + 18 sec at which time both stabilized. Test cell conditions for this firing were comparable to those of firing 09A and thus affected thrust chamber chilldown rates and engine operation as for 09A. Transient side loads were again less than ±500 lb_f.

4.2.3 Firing J4-1902-10A

Firing 10A consisted of 125 sec of idle mode. Test period 10 was conducted with a 1.5-in.-diam orifice installed in the thrust chamber fuel bypass line as opposed to the 1.751-in.-diam orifice used on test period 09. Fuel bypass flow was reduced to zero by closing the bypass valve at t_0 + 100 sec on this firing. The effect of the bypass valve closing is seen in Figs. 19 and 20, by increased oscillations in chamber pressure and by a reduction in total propellant flow rate and an increase in mixture ratio.

The fuel at the injector reached saturation (two phase conditions) at t_0 + 30 sec, and fuel injection density reached 0.141 lb_m/ft^3 at t_0 + 100 sec and 0.055 lb_m/ft^3 at t_0 + 125 sec with the bypass valve closed. Characteristic velocity was 2824 and 2955 ft/sec at these times. The increase in characteristic velocity was about 2.6 percent above that

on firing 07A which is the only directly comparable data from the inner 4 rows injector tests of Ref. 2. Transient side loads were less than ±500 lb_f.

4.2.4 Firing J4-1902-10B

Firing 10B consisted of 100 sec of idle-mode operation. The reduction in total fuel flow on this firing resulted in 20-sec additional time required to attain saturated fuel conditions at the injector. Total propellant flow rate and mixture ratio values were comparable to those of firing 10A. Chamber pressure exhibited the same type of oscillations seen on firing 10A with the bypass closed.

The fuel injection density attained on this firing was 0.108 lb_m/ft^3 at 100 sec, and characteristic velocity was 2814 ft/sec.

The thrust chamber chilldown rate was affected beginning at about t_0 + 23 sec by an increase in test cell ambient pressure and temperature as for firings 09A and 09B. Transient side loads were less than ±500 lb_f.

4.2.5 Firing J4-1902-10C

Firing 10C was of 60-sec duration with fuel and oxidizer inlet pressures of 40 and 30 psia, respectively. This firing exhibited saturated conditions at the fuel injector by t_0 + 15 sec and a fuel injection density of 0.262 lb_m/ft at t_0 + 60 sec. Characteristic velocity was 2954 ft/sec at t_0 + 60 sec. These results are also comparable to those of Ref. 2. Transient side loads were less than ±500 lb_f.

4.3 CHAMBER PRESSURE OSCILLATIONS

Engine chamber pressure oscillations are generally experienced during the idle-mode starting transient. Oscillations also occur at various other times during idle-mode operation; although for some firings after the starting transient, no oscillations of the type discussed here occur. The oscillations experienced during buildup to steady state are approximately ±2 to ±4 psi at frequencies of 1 to 2 Hz. Oscillations of these same magnitudes at varying frequencies up to about 14 Hz also occur whenever fuel injection density is low (0.15 lb_m/ft^3). Frequencies of 10 to 14 Hz occurred on firing 10A when the bypass valve was closed. Figure 34 shows these oscillation characteristics on firing 10A.

SECTION V
SUMMARY OF RESULTS

The results of five idle-mode firings of the J-2S rocket engine conducted during tests J4-1902-09 and 10 on April 17 and 24, 1969, are summarized as follows:

1. Performance of the row 10 idle-mode compartmented injector was not significantly improved over the inner 4 rows injector. The characteristic velocity increase was 2.6 percent for the only directly comparable test.
2. Calculated fuel injection density for the row 10 injector was lowest for firing 10A at 0.055 lb_m/ft^3 with the fuel bypass valve closed and 0.141 lb_m/ft^3 with the fuel bypass valve open.
3. Chamber pressure oscillations were present during steady-state, idle-mode operation when fuel injection density was less than 0.15 lb_m/ft^3 (firings 10A and 10B).
4. Saturated fuel (two phase conditions) was attained at times ranging from 15 to 55 sec after engine start command.
5. Engine side loads measured during these firings did not exceed ±500 lb_f.

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APPENDIXES

I. ILLUSTRATIONS
II. TABLES
III. INSTRUMENTATION
IV. METHOD OF CALCULATIONS

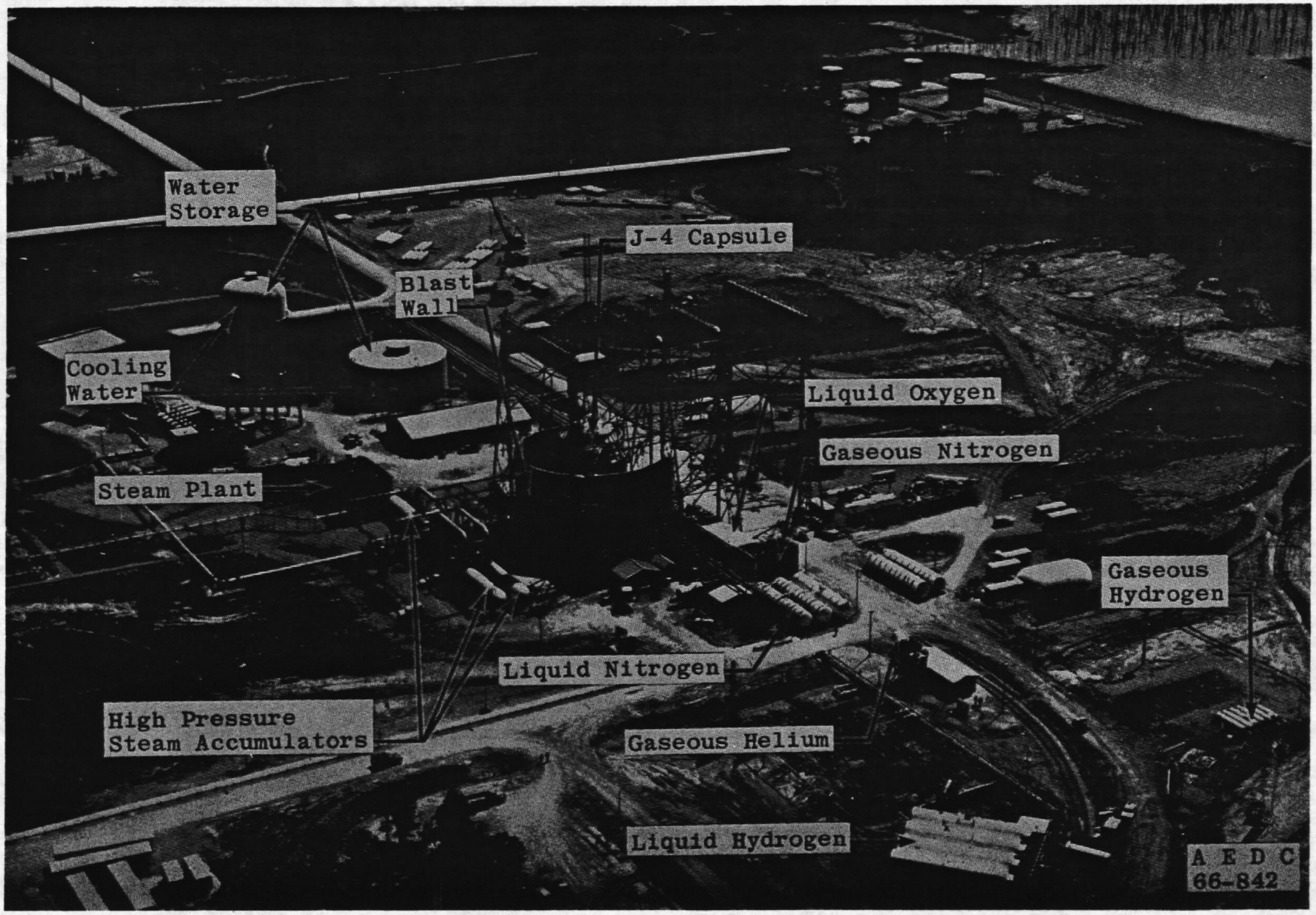


Fig. 1 Test Cell J-4 Complex

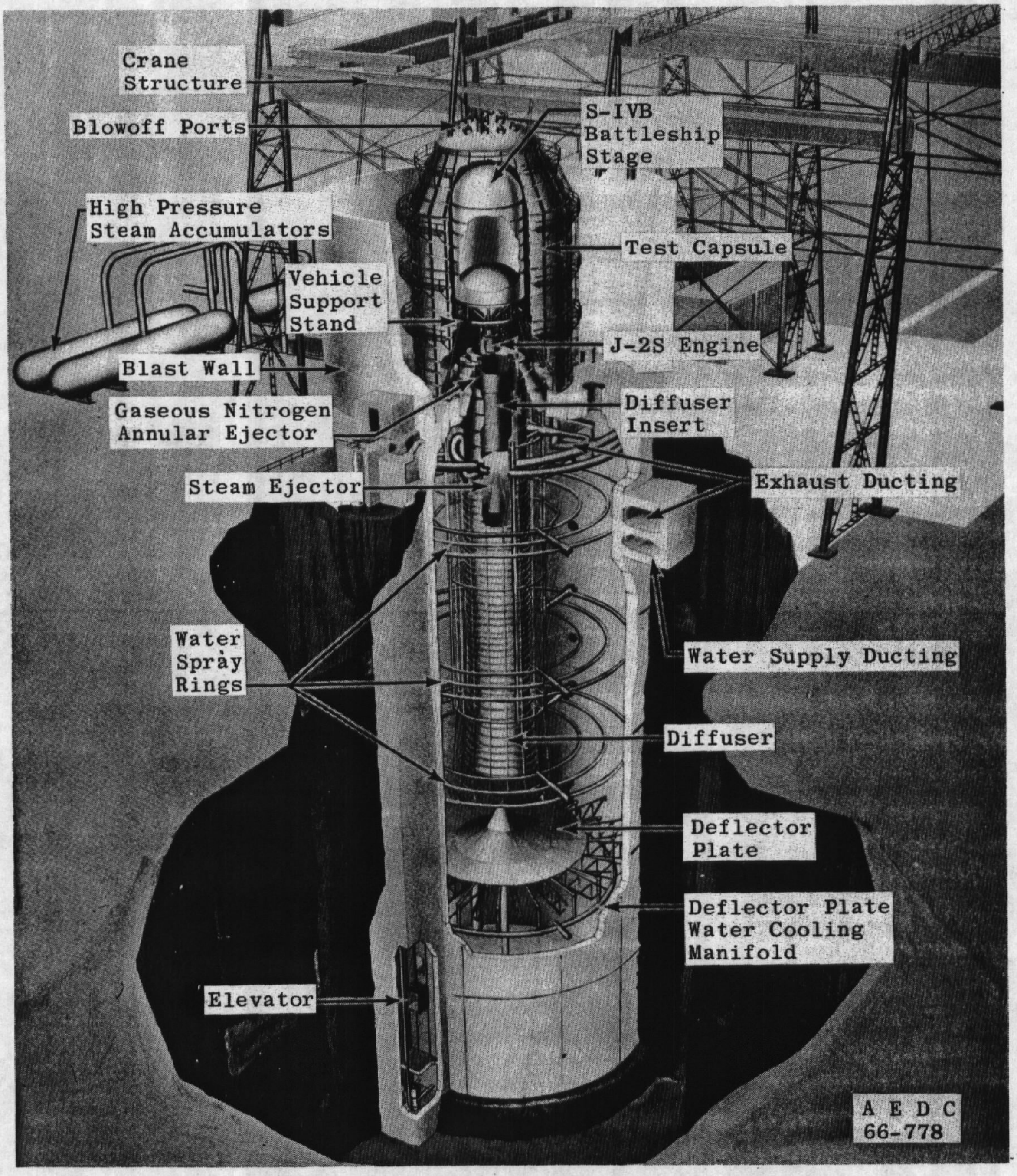


Fig. 2 Test Cell J-4, Artist's Conception

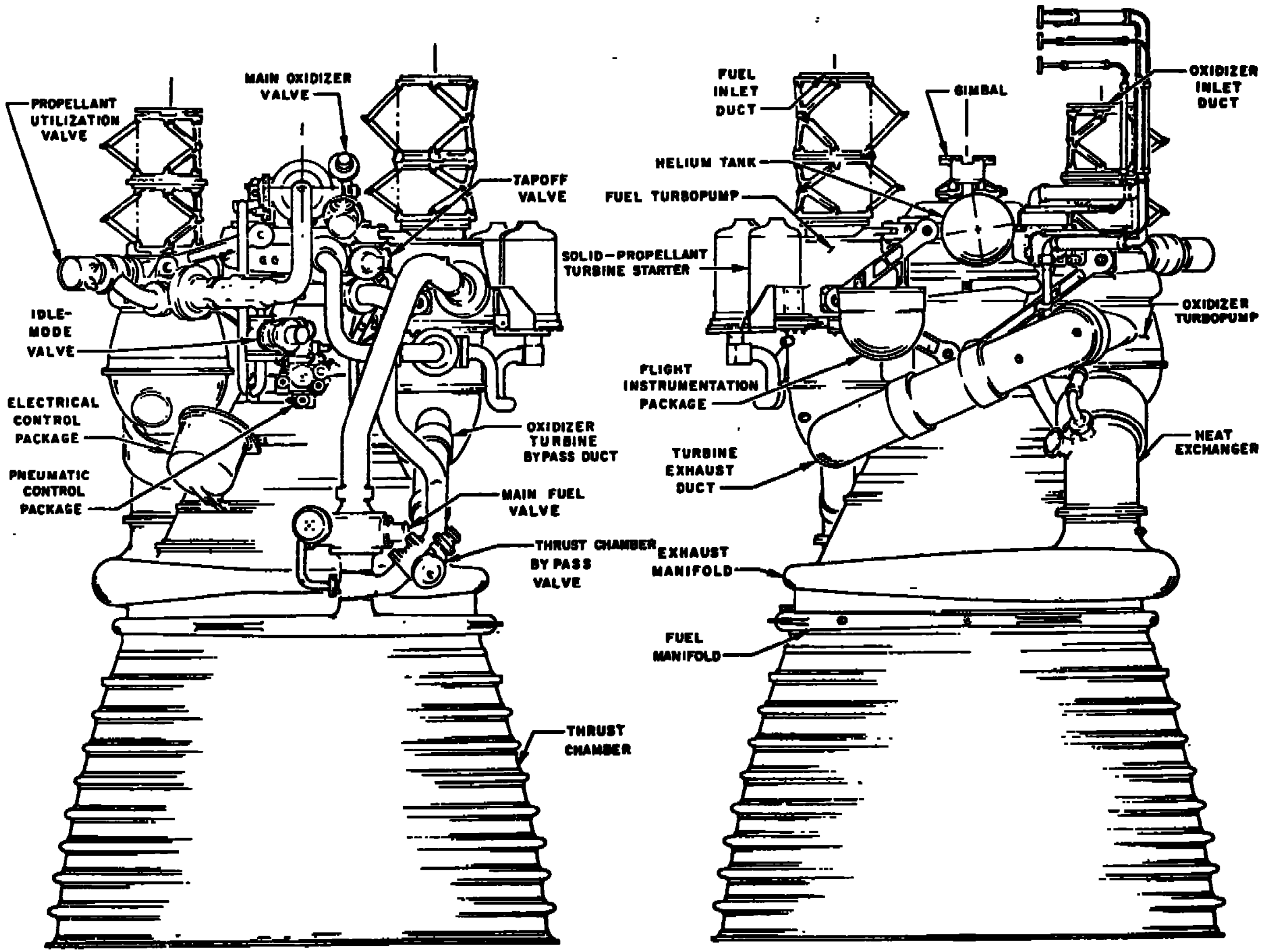


Fig. 3 J-2S Engine General Arrangement

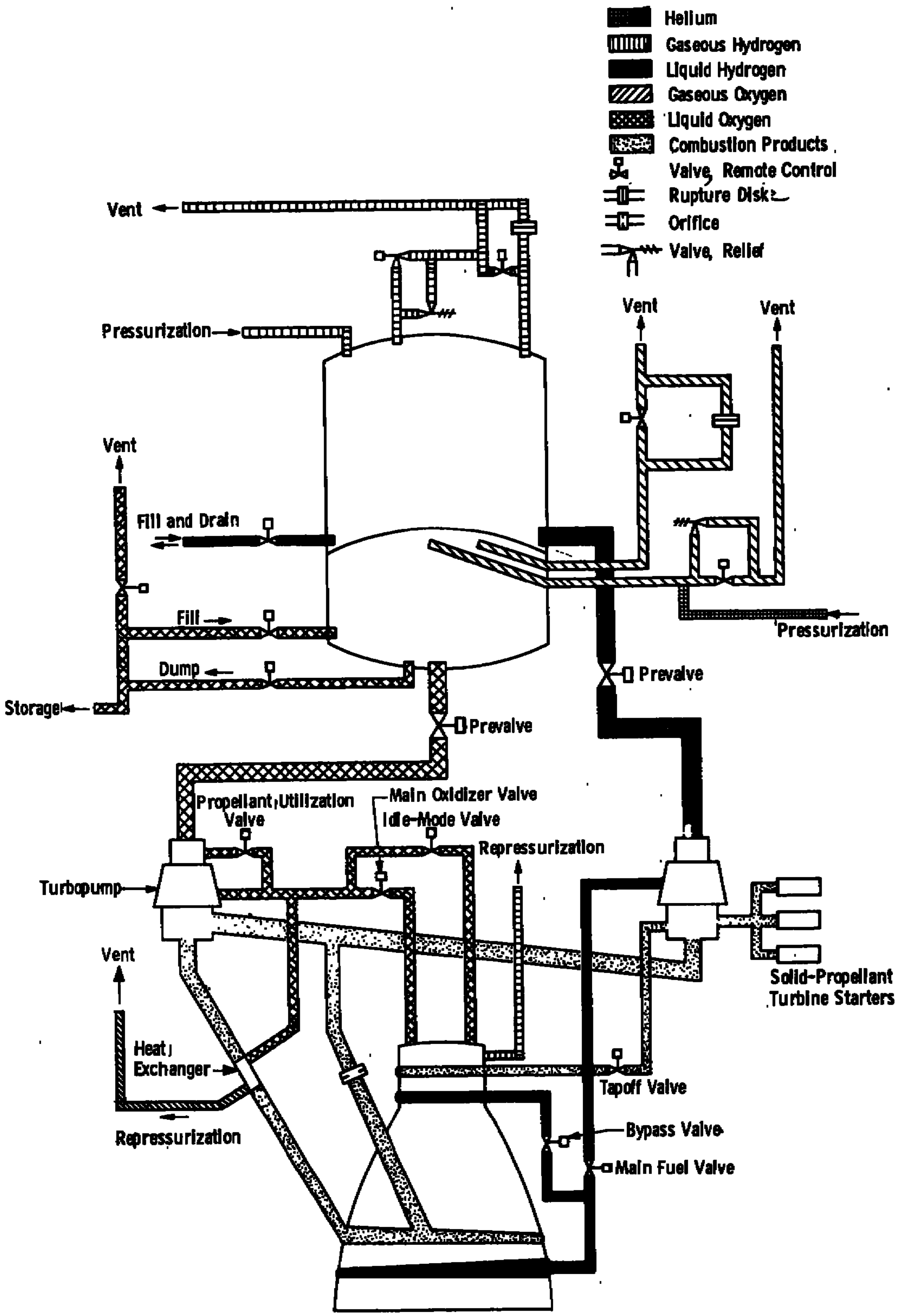
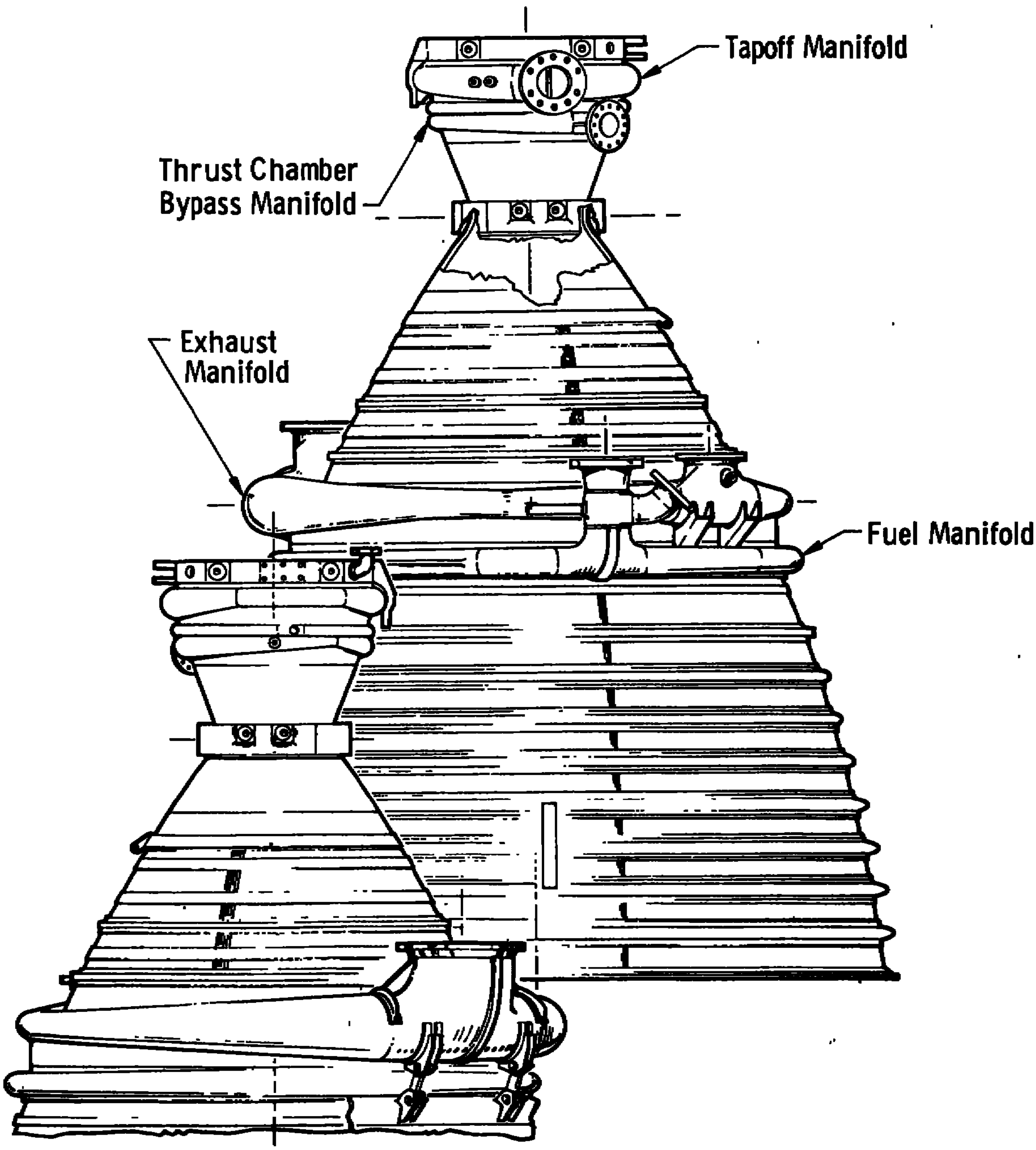
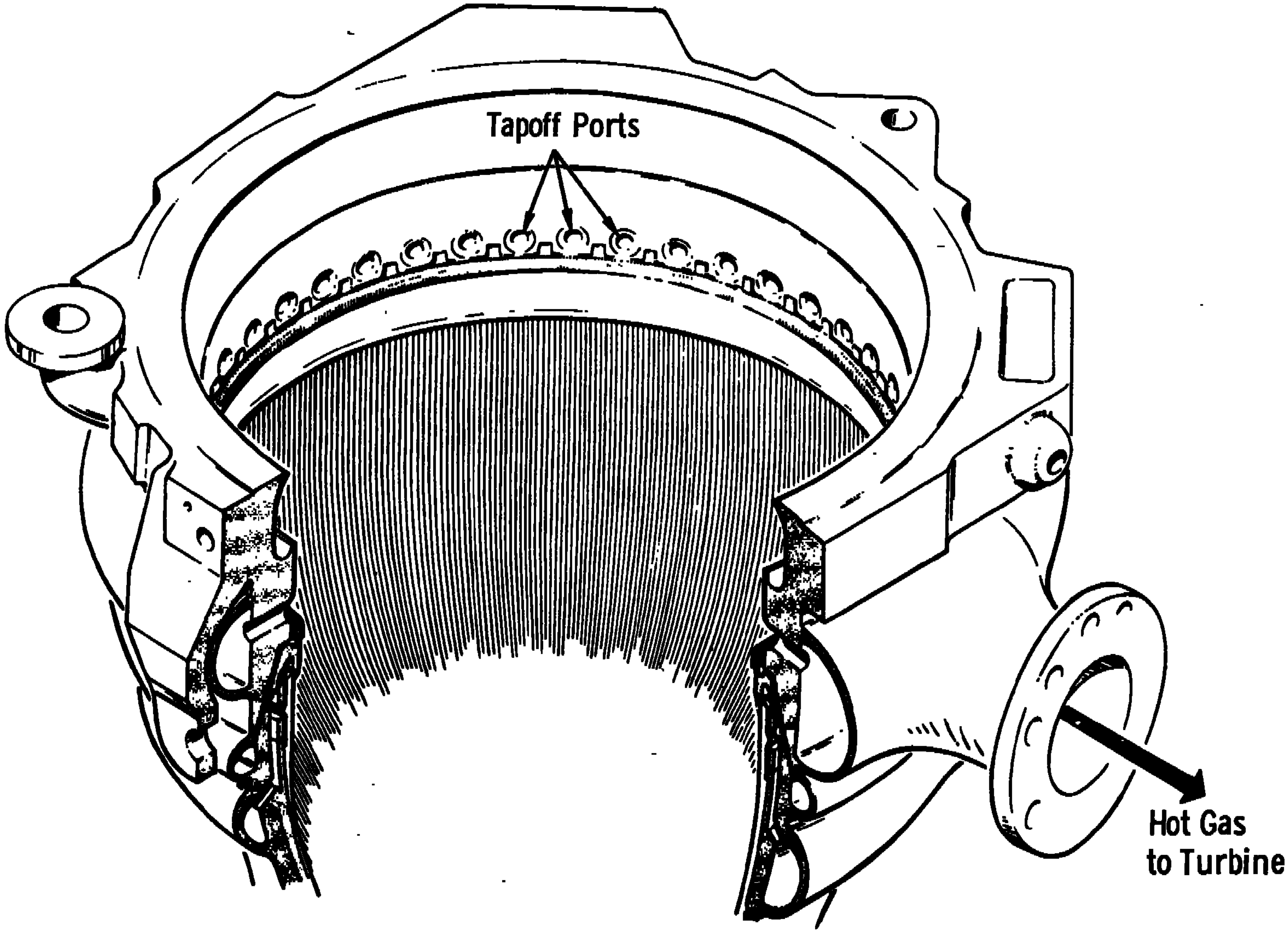


Fig. 4 S-IVB Battleship Stage/J-2S Engine Schematic

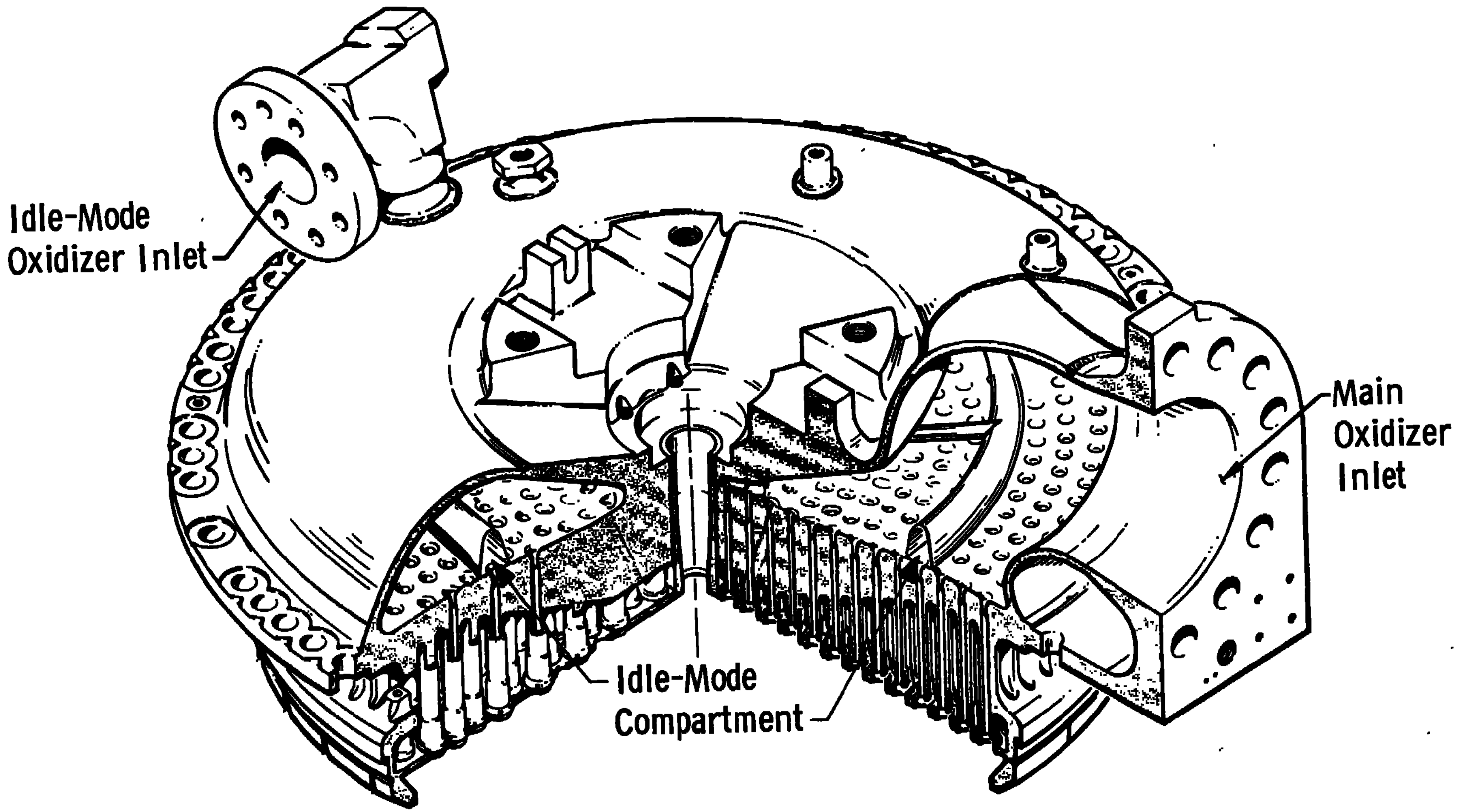


a. Thrust Chamber

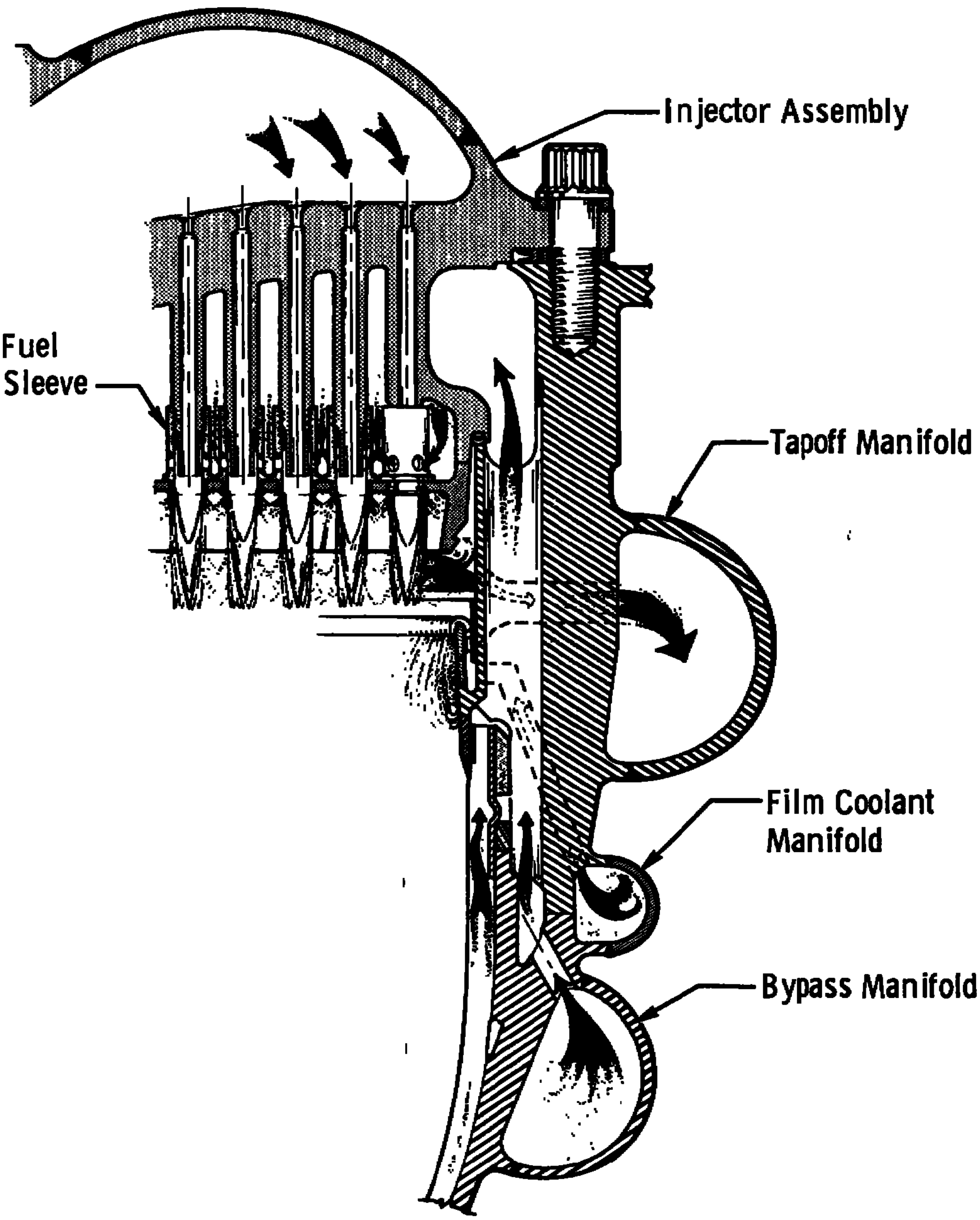
Fig. 5 Engine Details



b. Combustion Chamber
Fig. 5 Continued



c. Injector
Fig. 5 Continued



d. Injector to Chamber
Fig. 5 Concluded

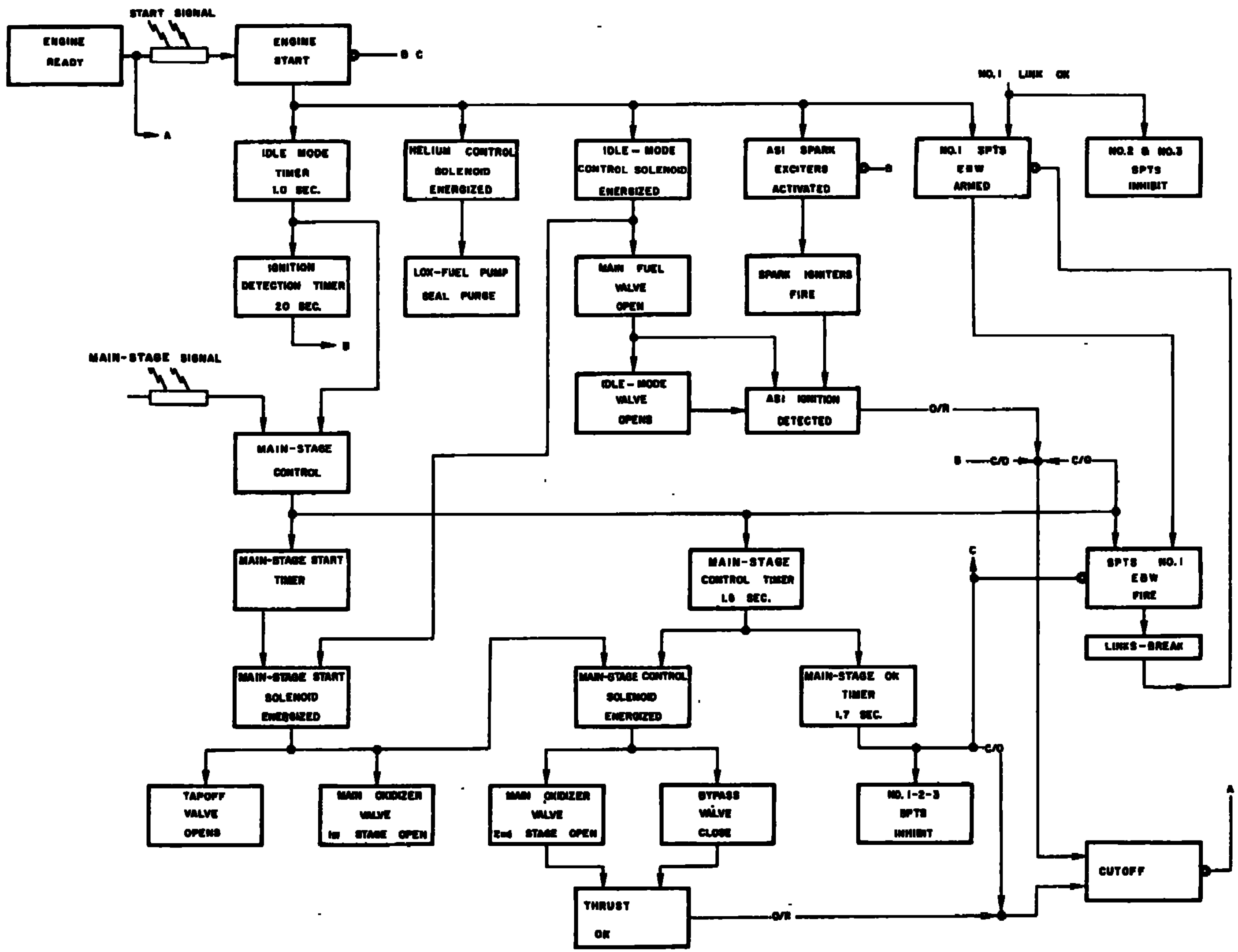
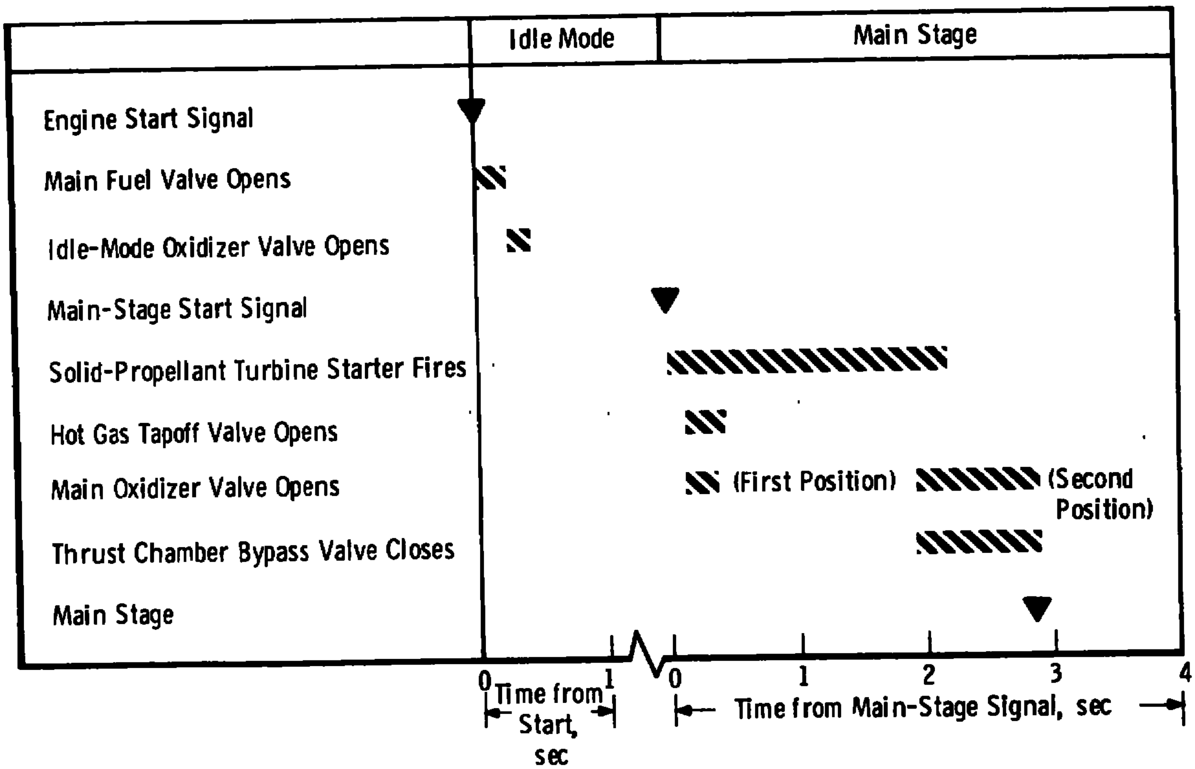
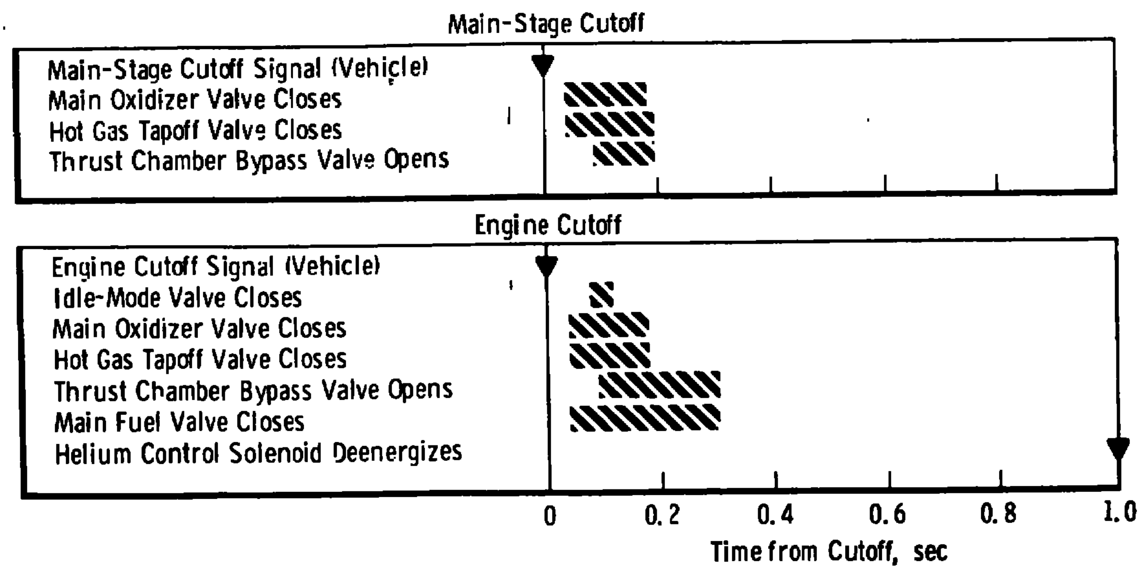


Fig. 6 Engine Start Logic Schematic

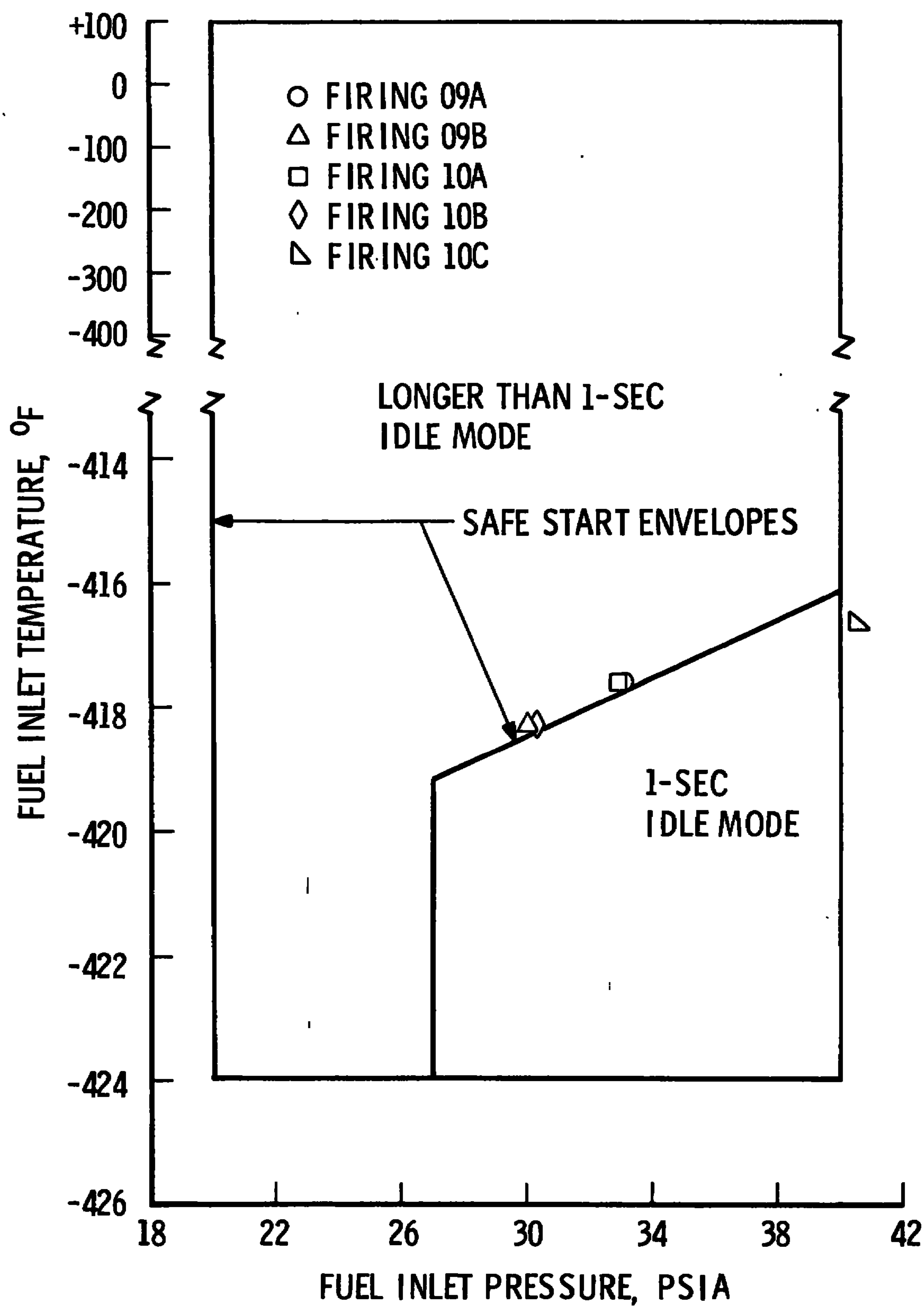


a. Start Sequence



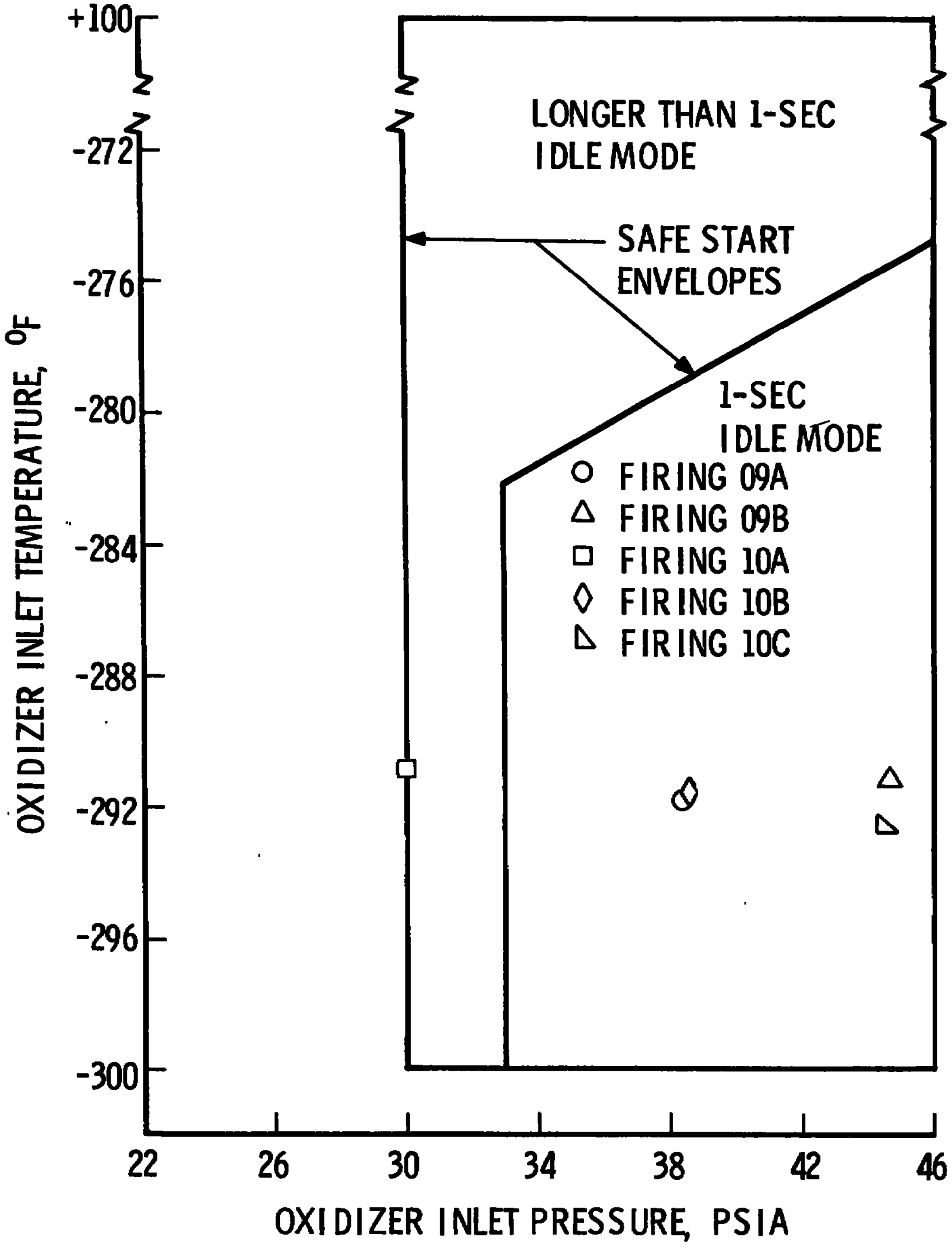
b. Shutdown Sequence

Fig. 7 Engine Start and Shutdown Sequence

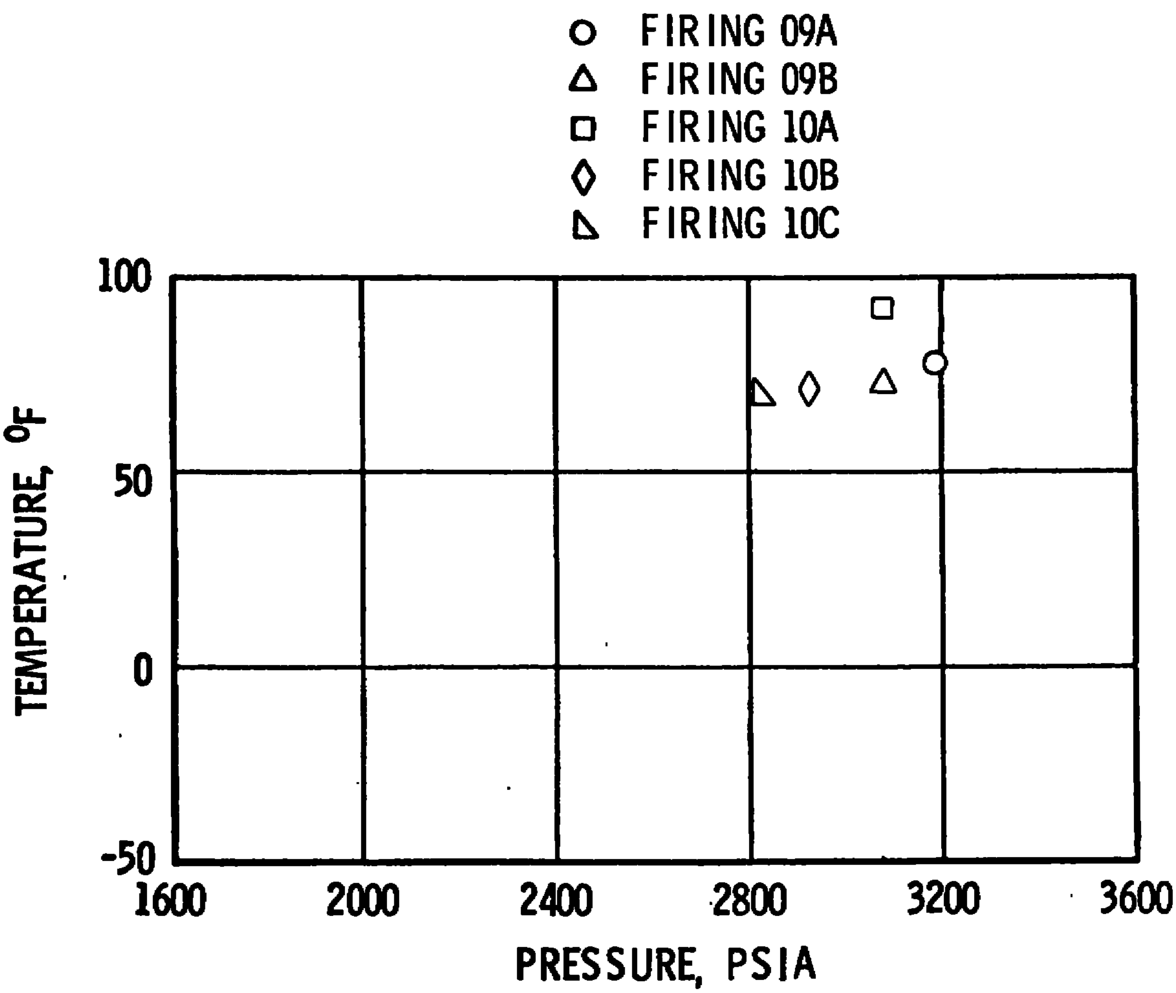


a. Fuel Pump

Fig. 8 Engine Start Conditions for Propellant Pump Inlets and Helium Tank



b. Oxidizer Pump
Fig. 8 Continued



c. Helium Tank
Fig. 8 Concluded

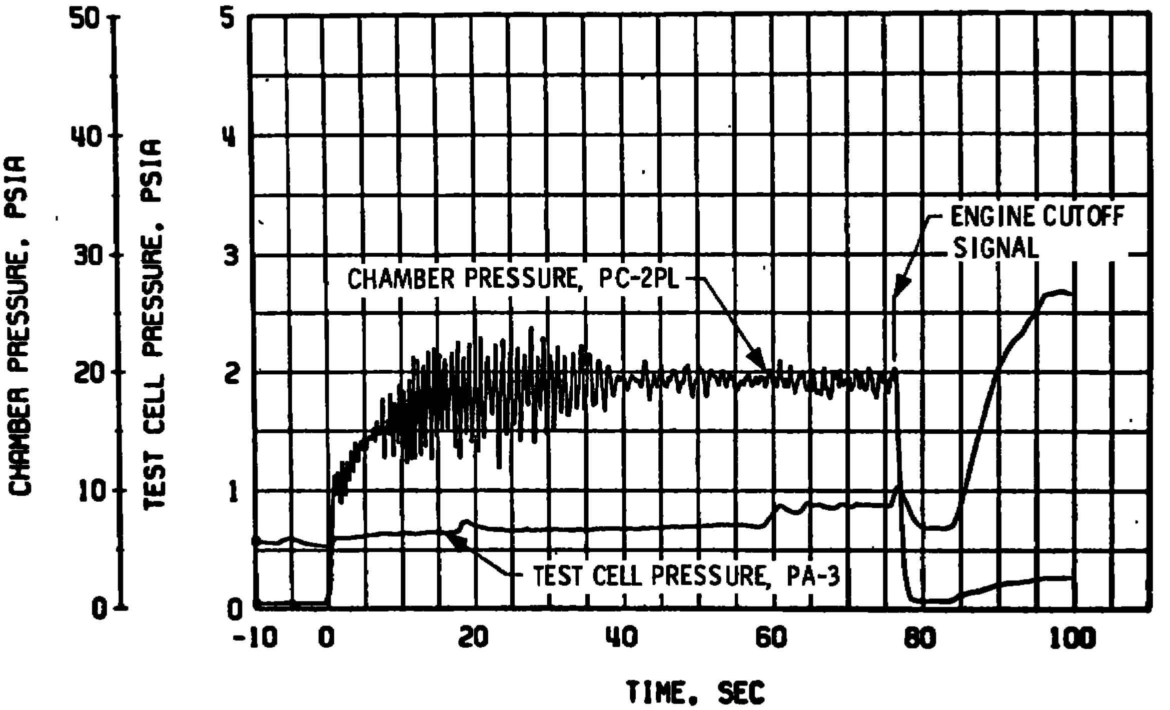


Fig. 9 Engine Ambient and Combustion Chamber Pressure, Firing 09A

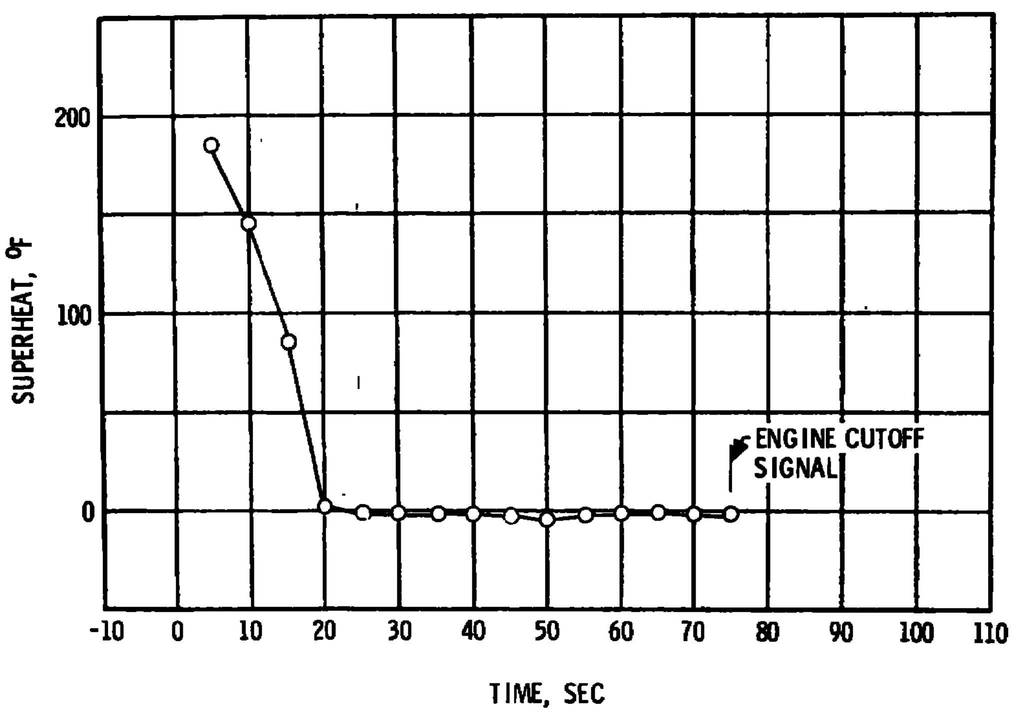


Fig. 10 Fuel Conditions at Injector, Firing 09A

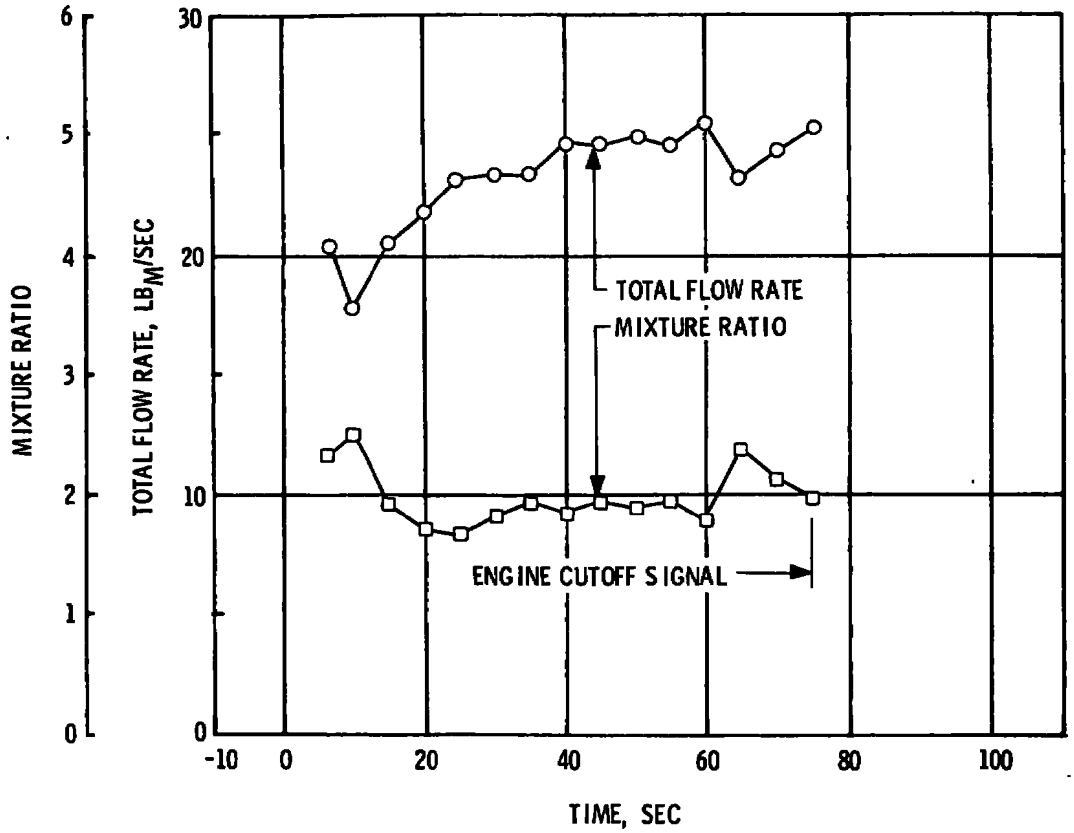


Fig. 11 Total Propellant Flow Rate and Mixture Ratio, Firing 09A

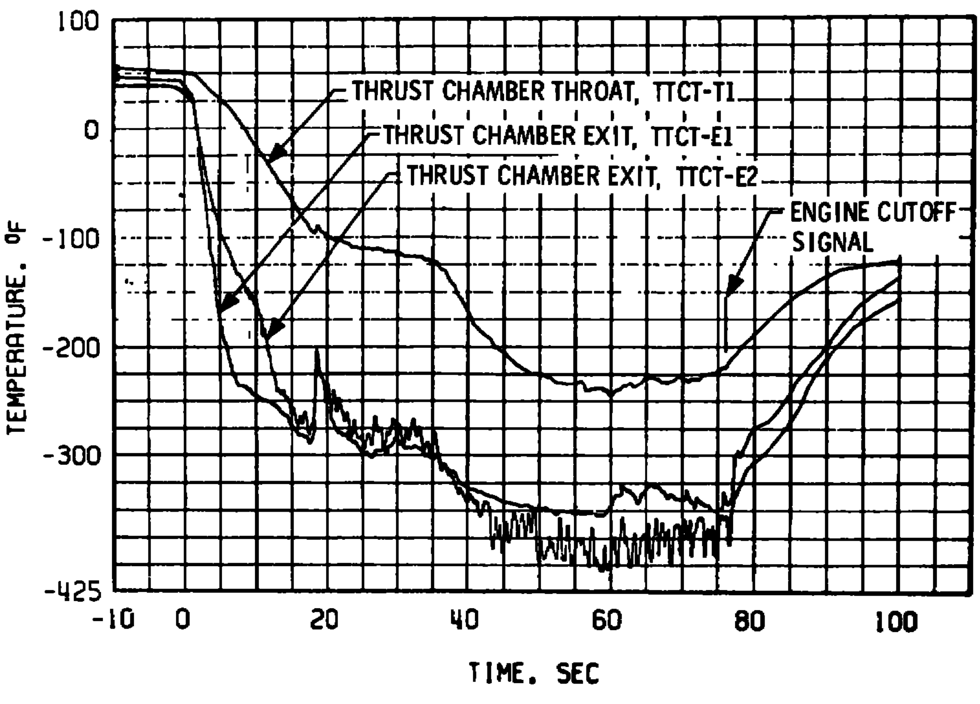


Fig. 12 Thrust Chamber Chilldown, Firing 09A

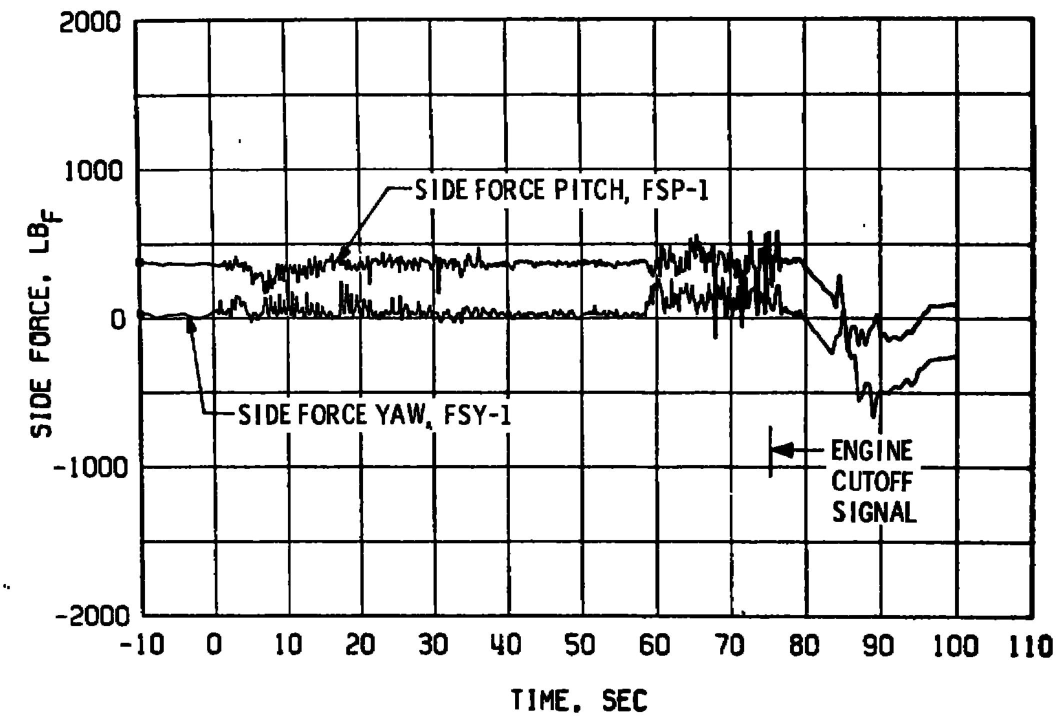


Fig. 13 Engine Side Forces, Firing 09A

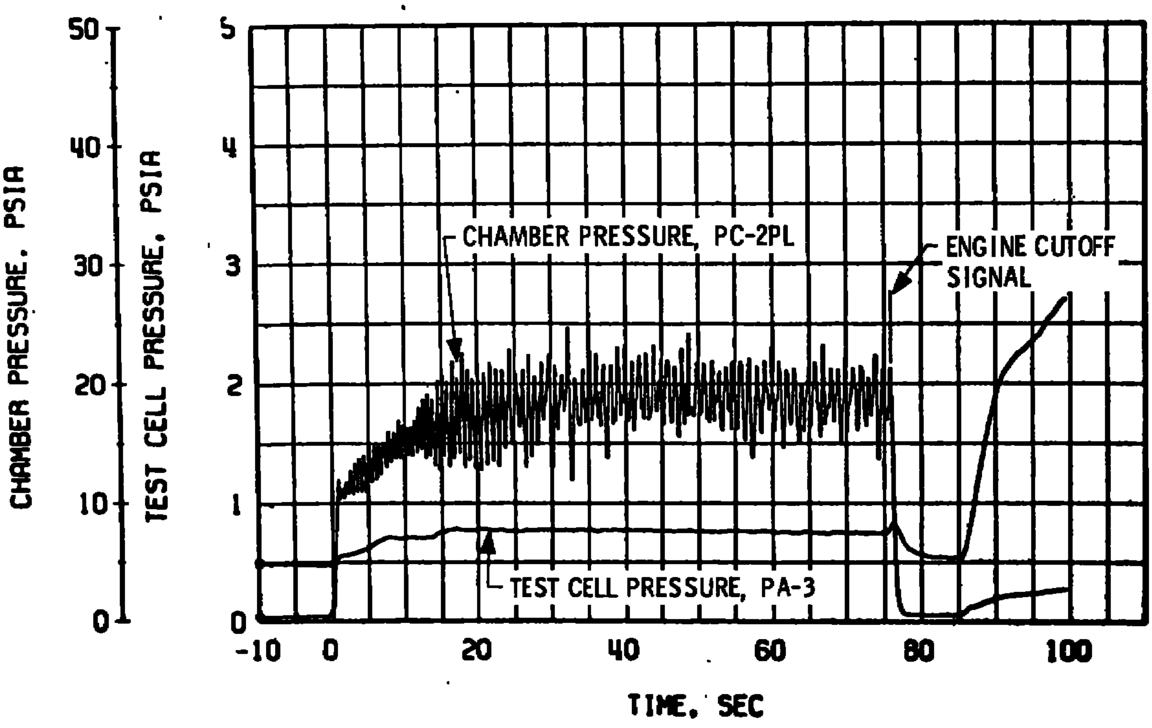


Fig. 14 Engine Ambient and Combustion Chamber Pressure, Firing 09B

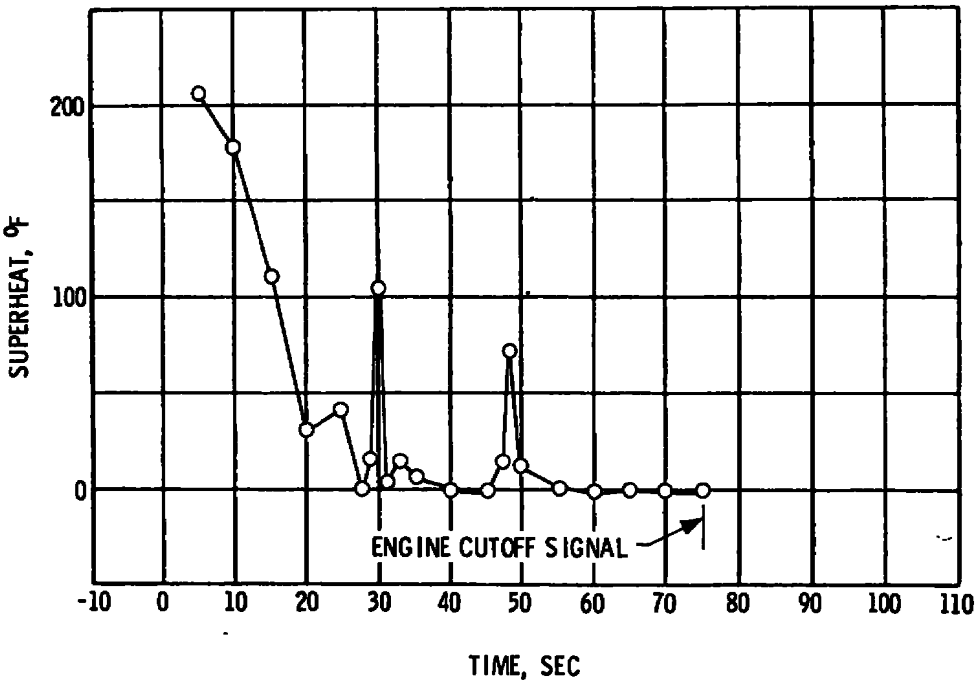


Fig. 15 Fuel Conditions at Injector, Firing 09B

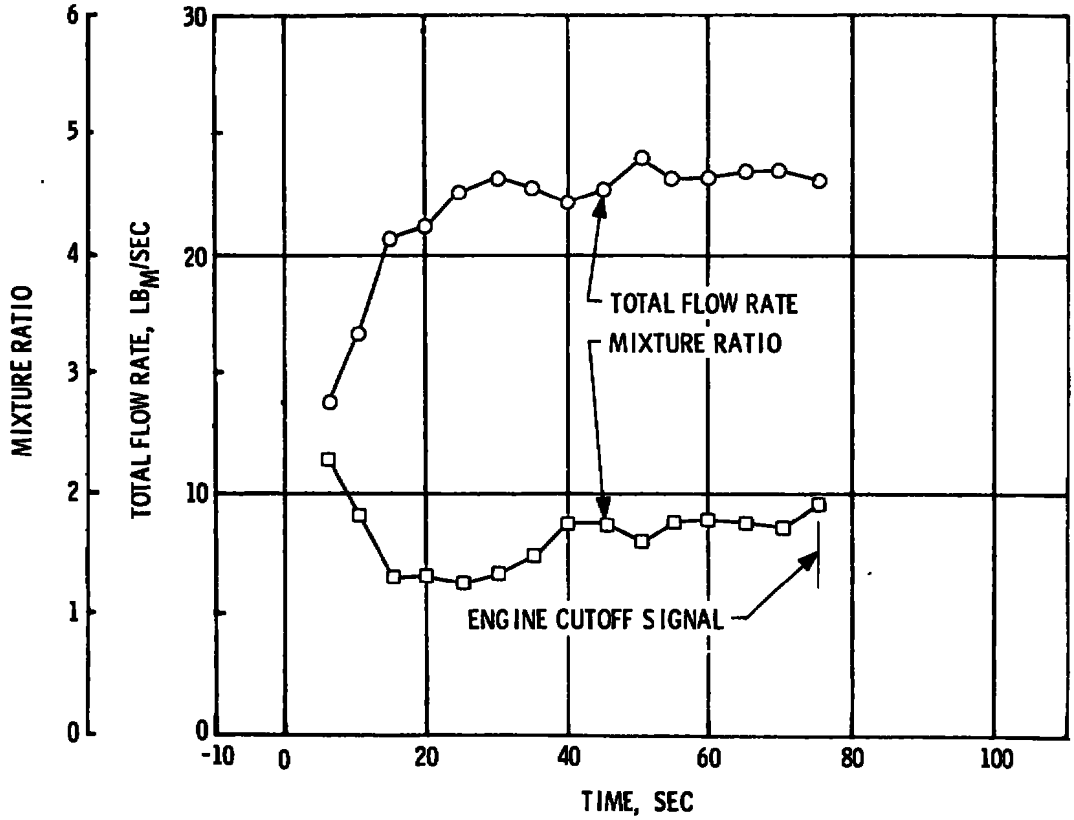


Fig. 16 Total Propellant Flow Rate and Mixture Ratio, Firing 09B

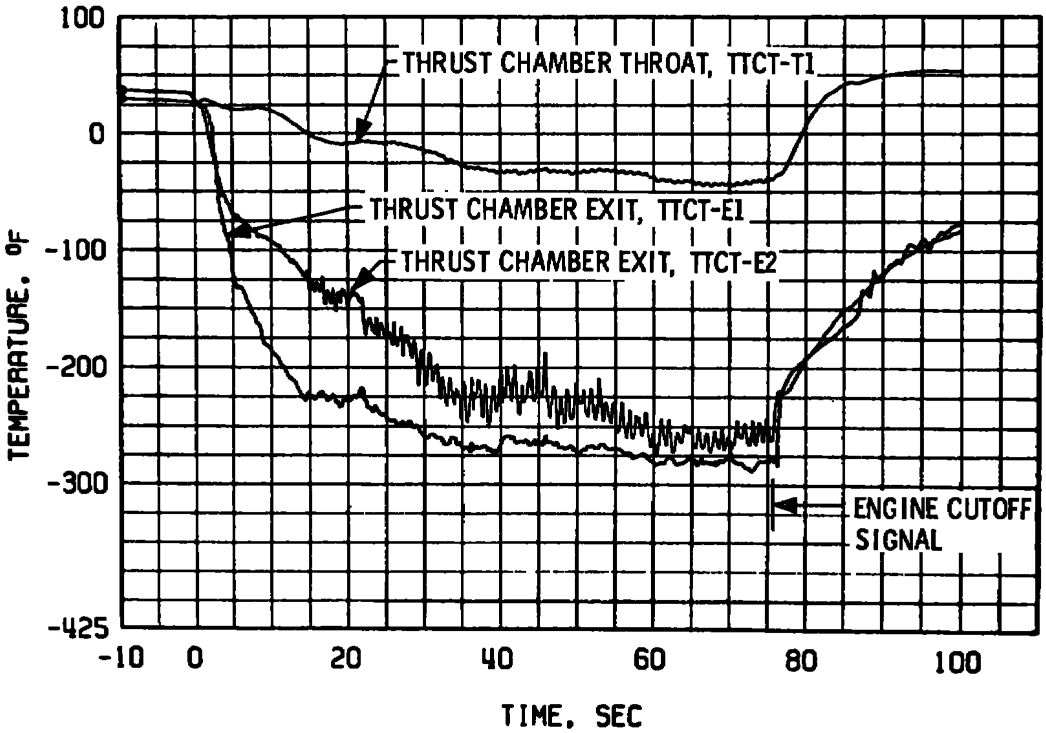


Fig. 17 Thrust Chamber Chilldown, Firing 09B

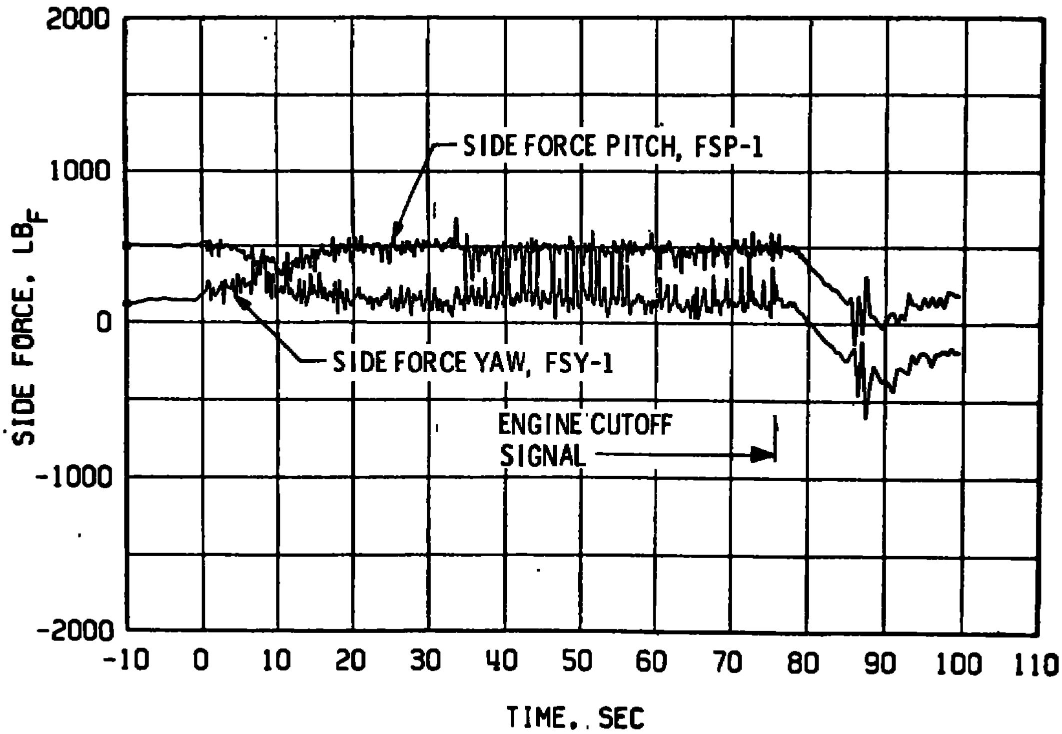


Fig. 18 Engine Side Forces, Firing 09B

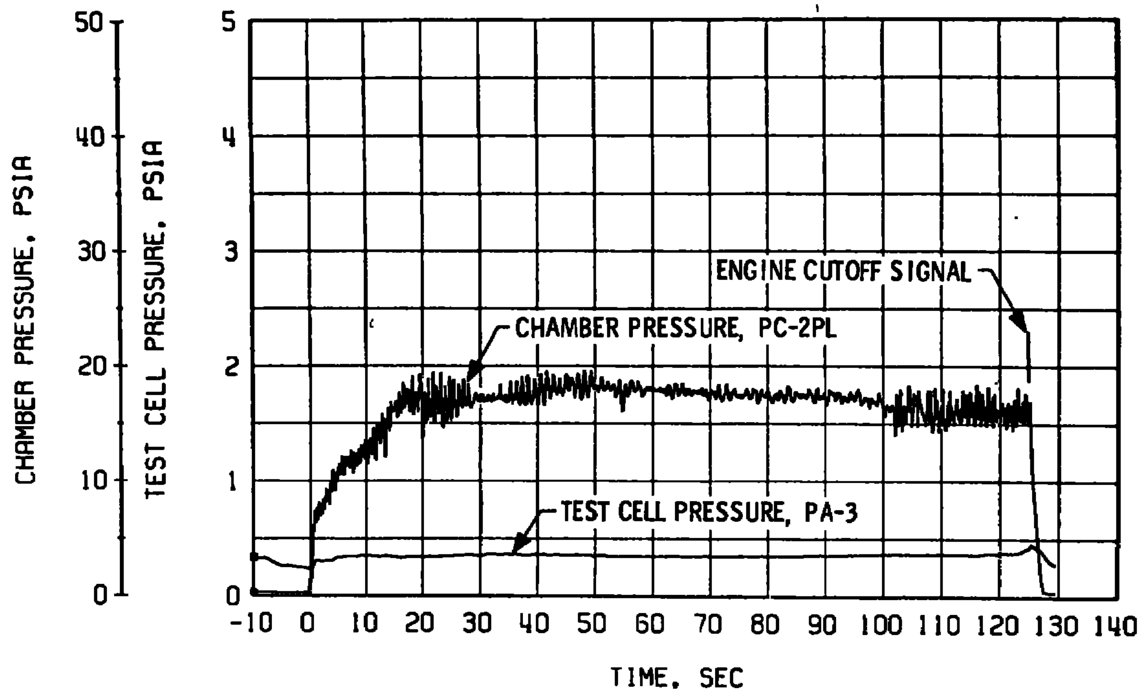


Fig. 19 Engine Ambient and Combustion Chamber Pressure, Firing 10A

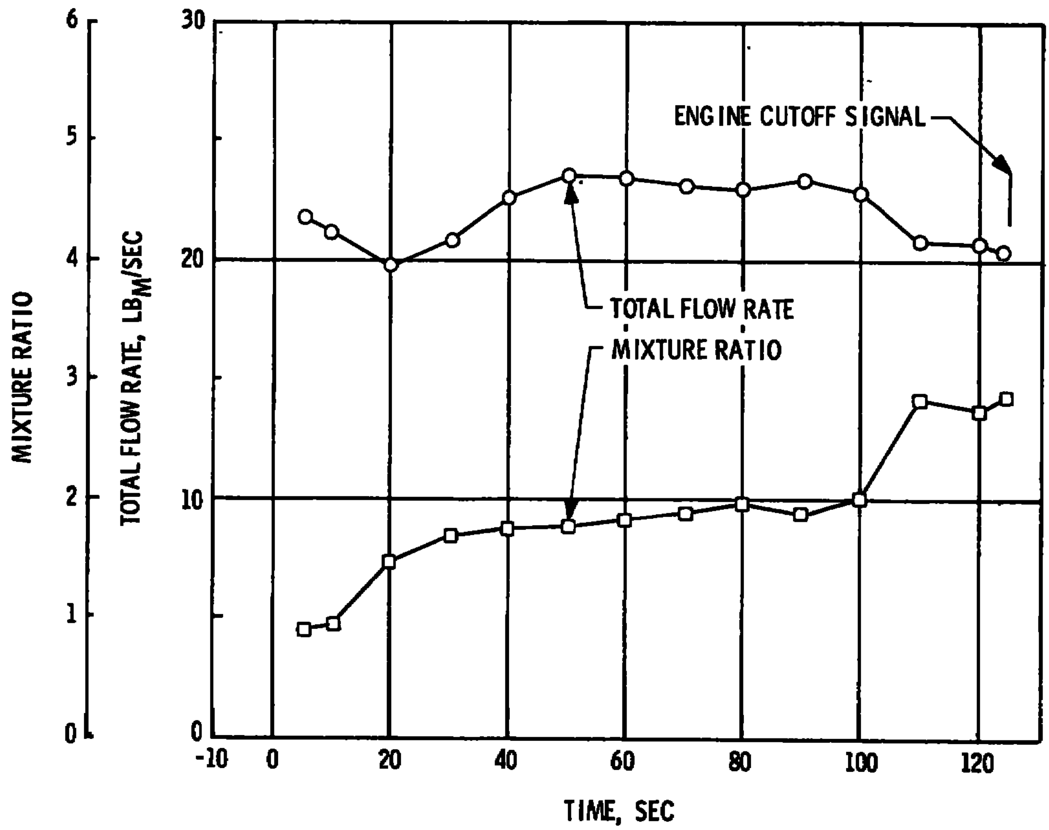


Fig. 20 Total Propellant Flow Rate and Mixture Ratio, Firing 10A

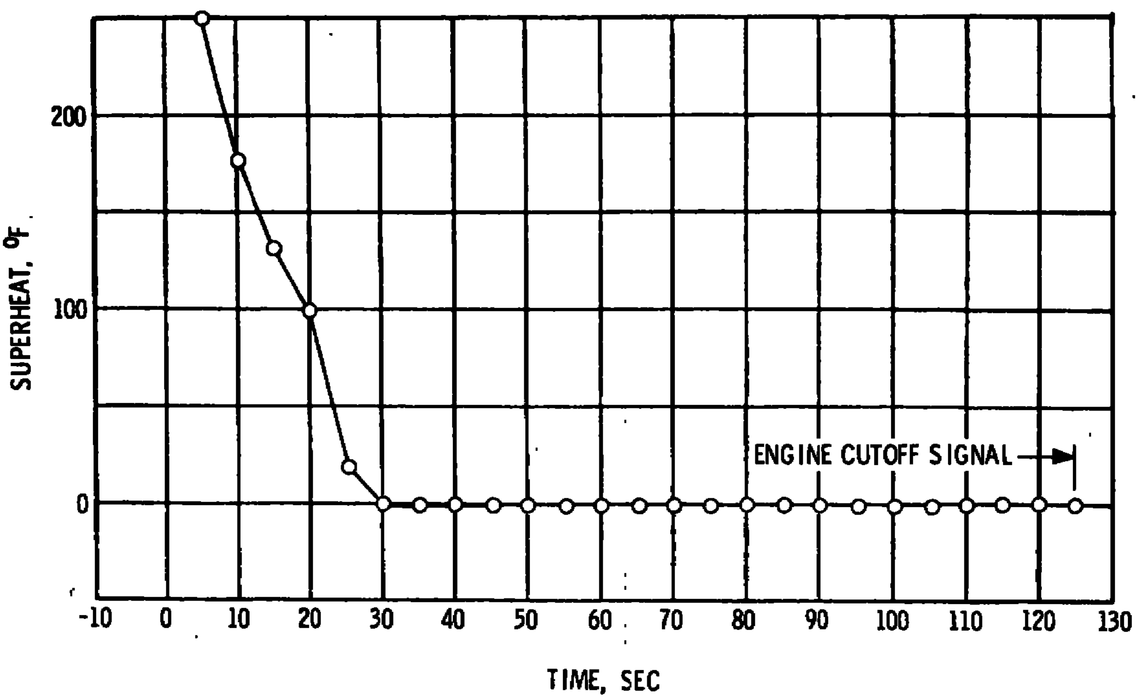


Fig. 21 Fuel Conditions at Injector, Firing 10A

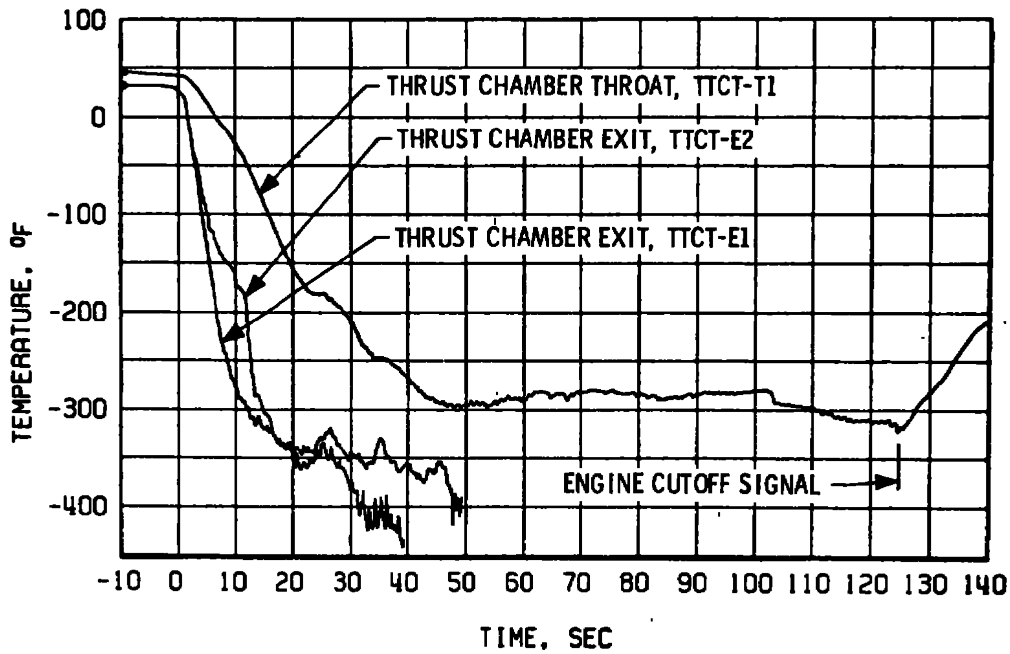


Fig. 22 Thrust Chamber Chilldown, Firing 10A

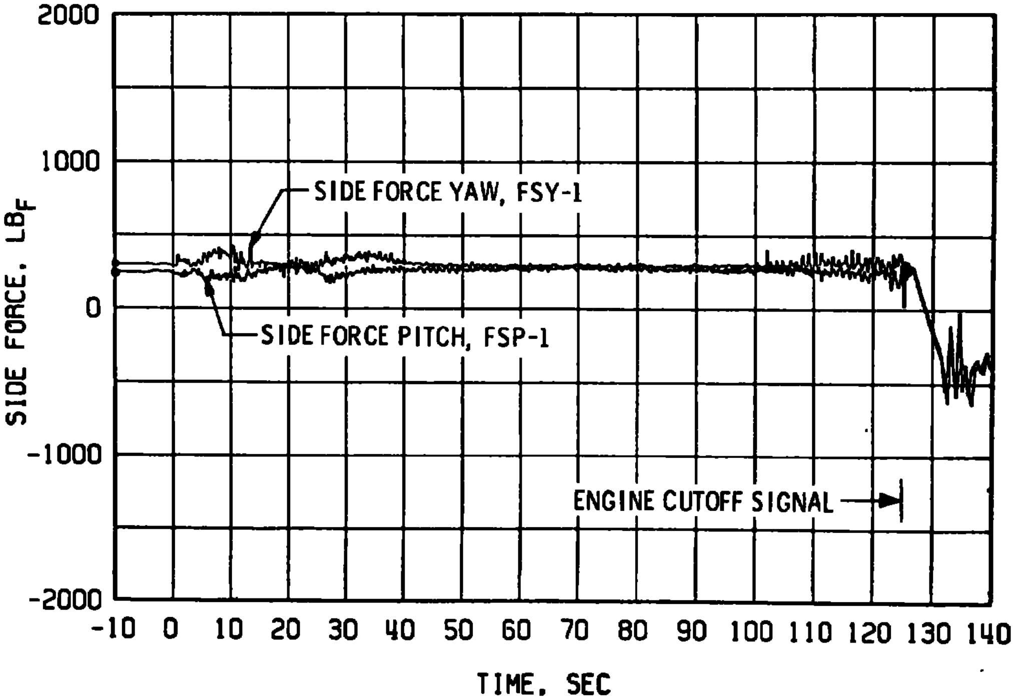


Fig. 23 Engine Side Forces, Firing 10A

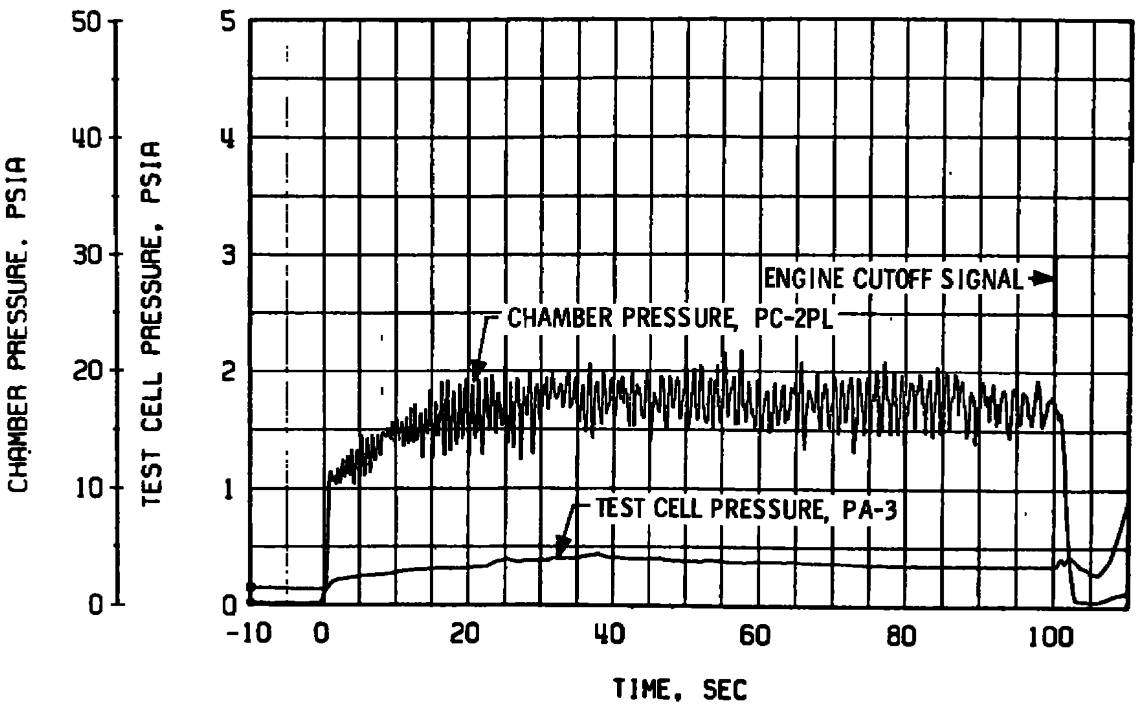


Fig. 24 Engine Ambient and Combustion Chamber Pressure, Firing 10B

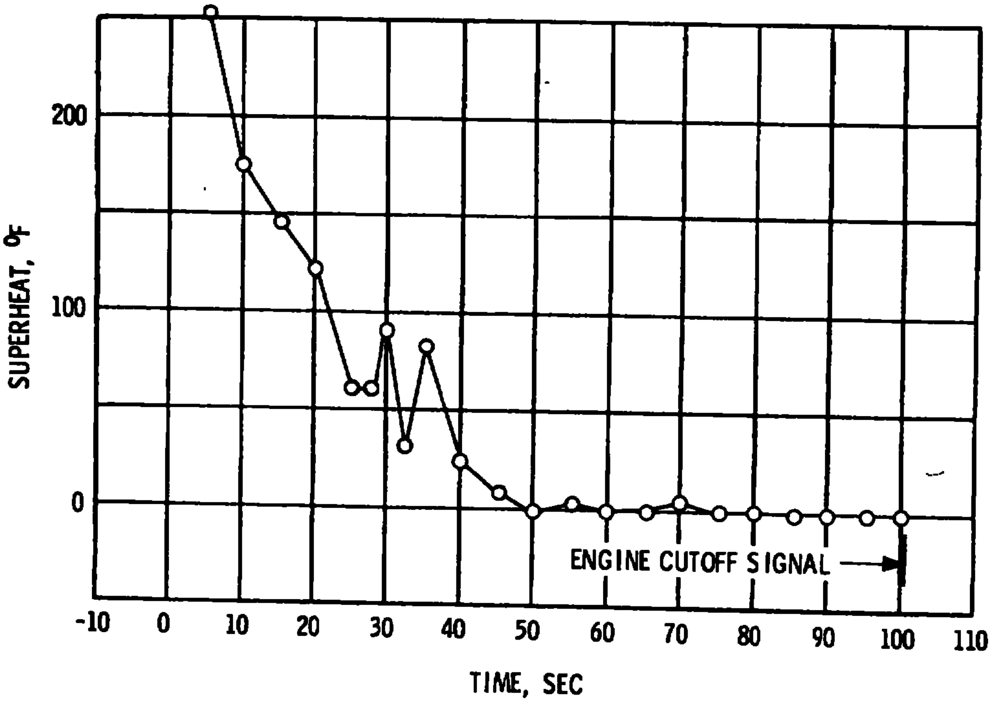


Fig. 25 Fuel Conditions at Injector, Firing 10B

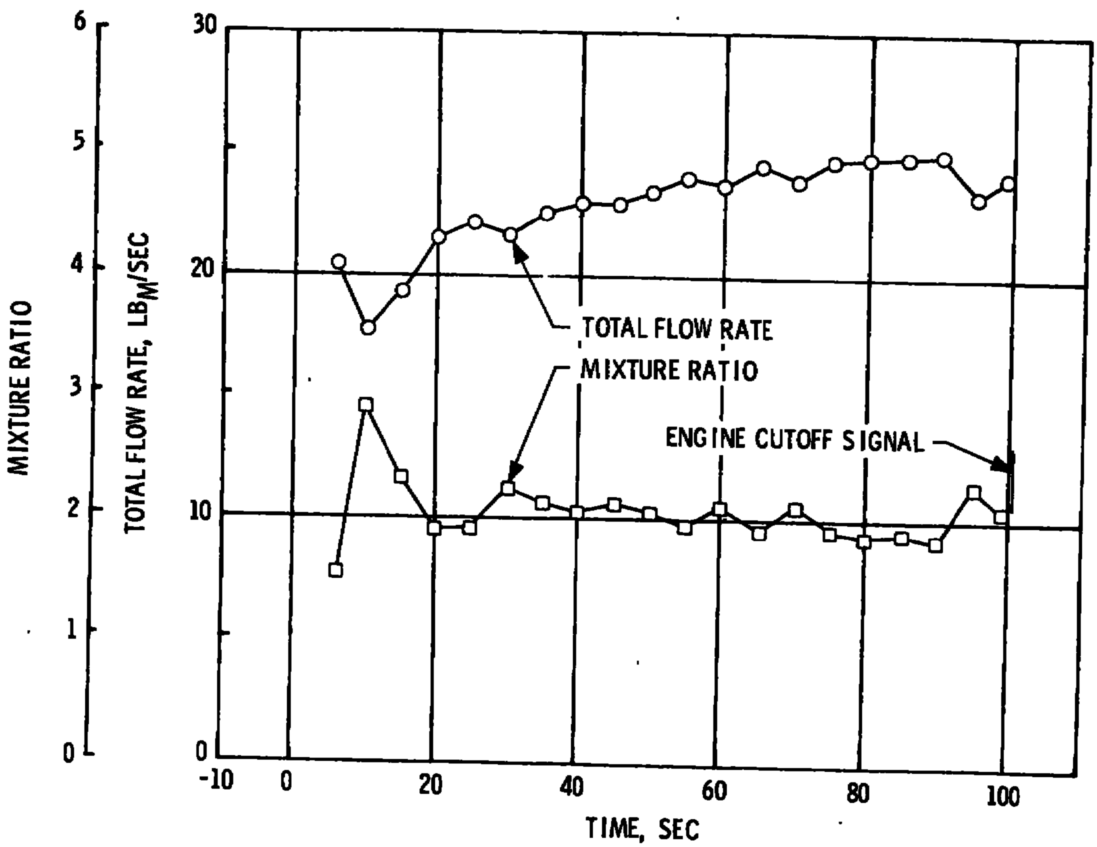


Fig. 26 Total Propellant Flow Rate and Mixture Ratio, Firing 10B

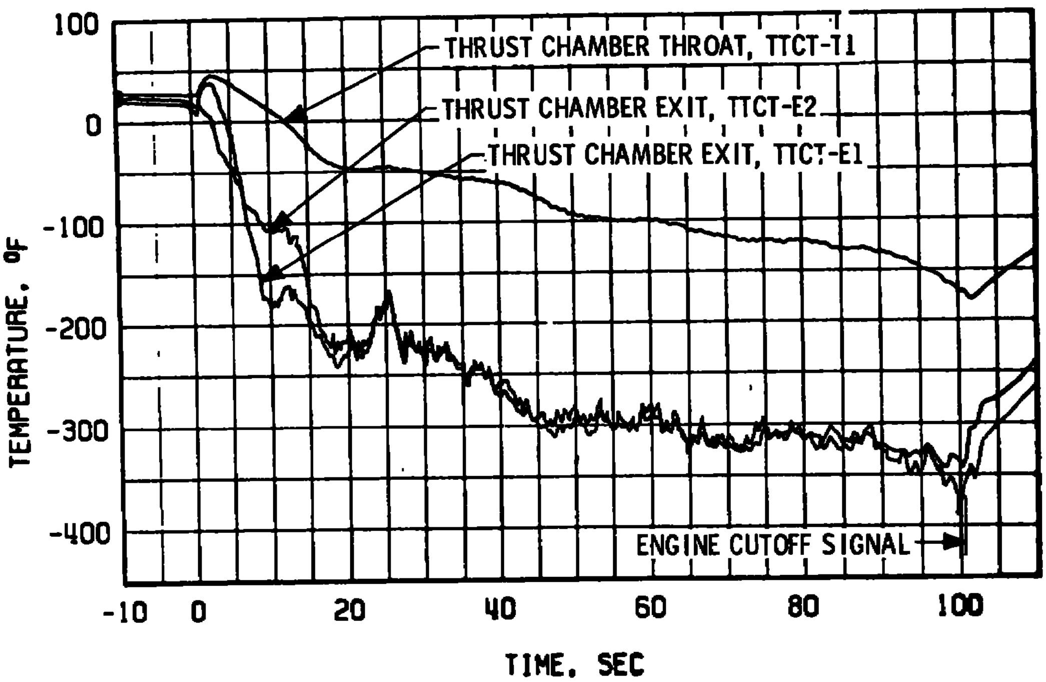


Fig. 27 Thrust Chamber Childown, Firing 10B

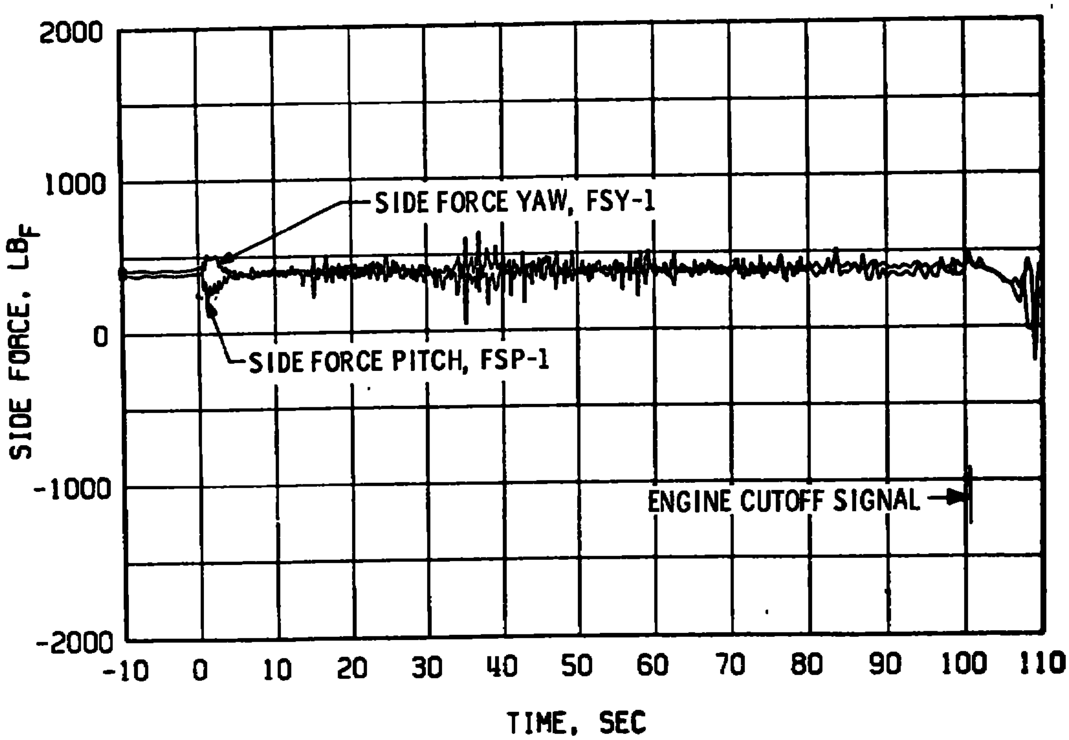


Fig. 28 Engine Side Forces, Firing 10B

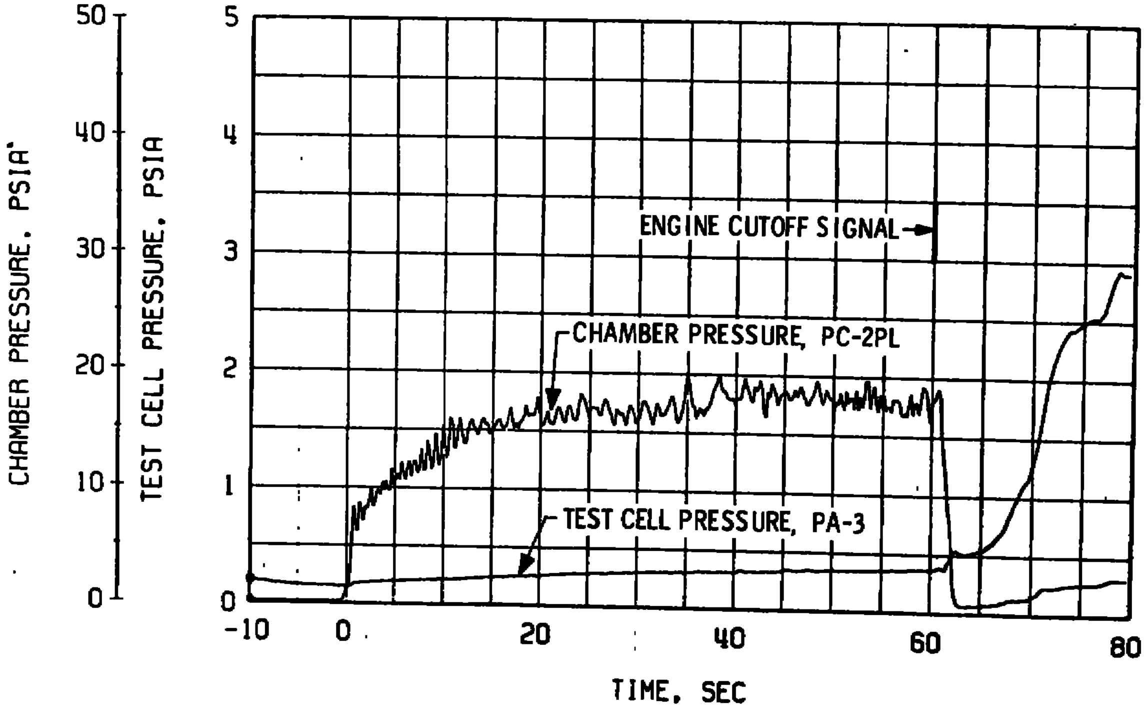


Fig. 29 Engine Ambient and Combustion Chamber Pressure, Firing 10C

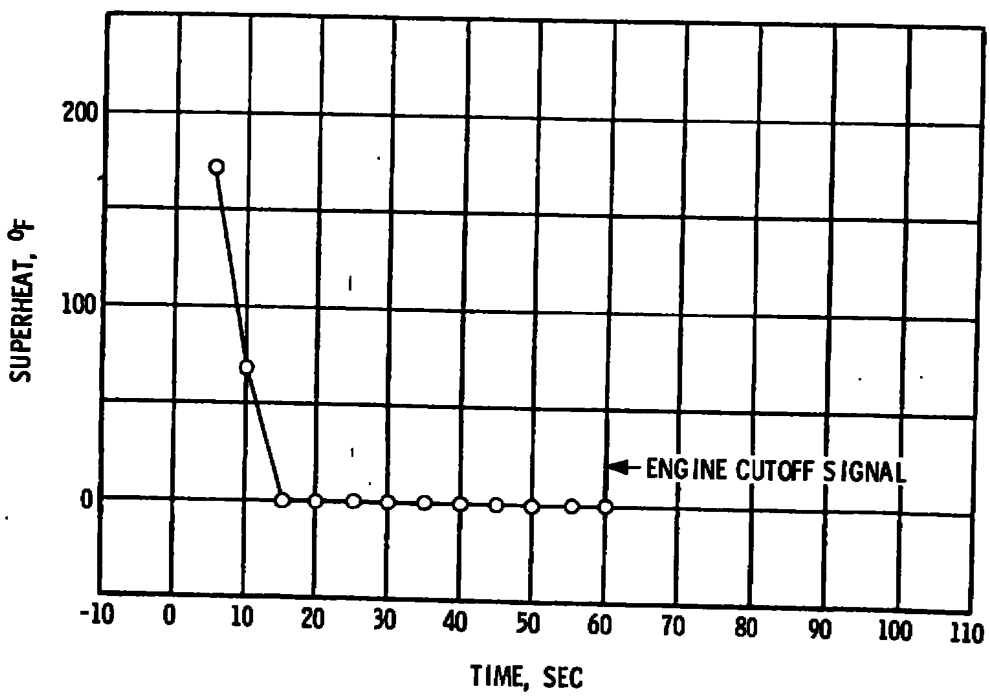


Fig. 30 Fuel Conditions at Injector, Firing 10C

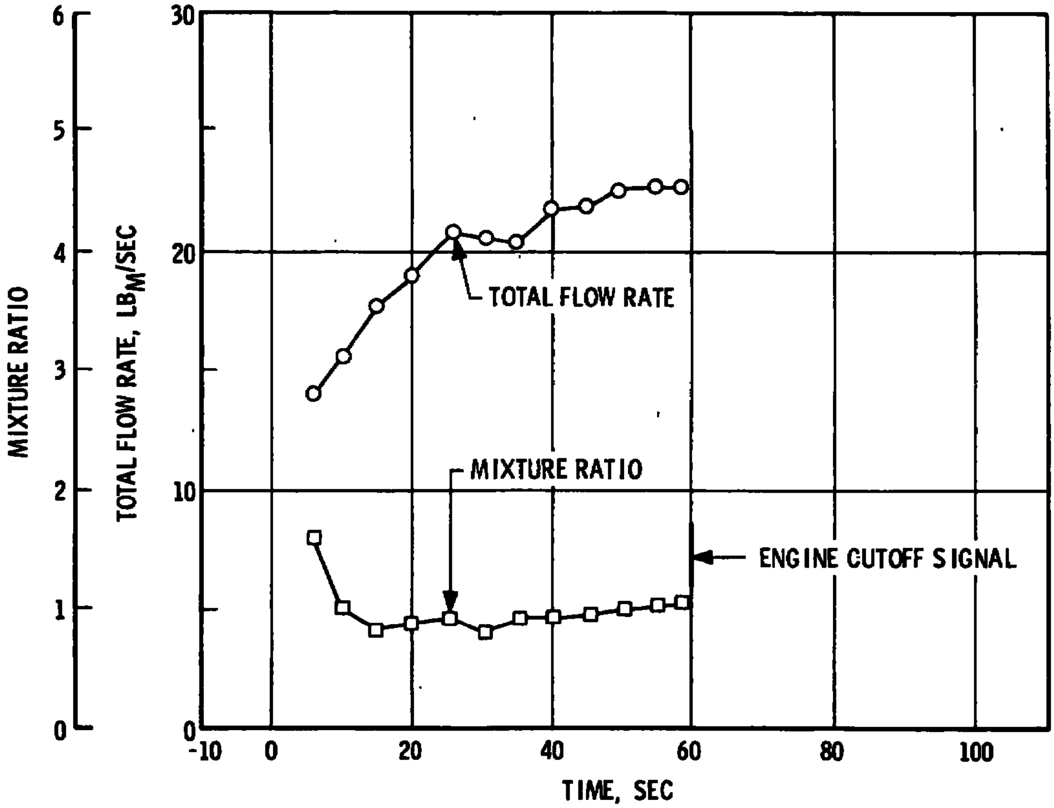


Fig. 31 Total Propellant Flow Rate and Mixture Ratio, Firing 10C

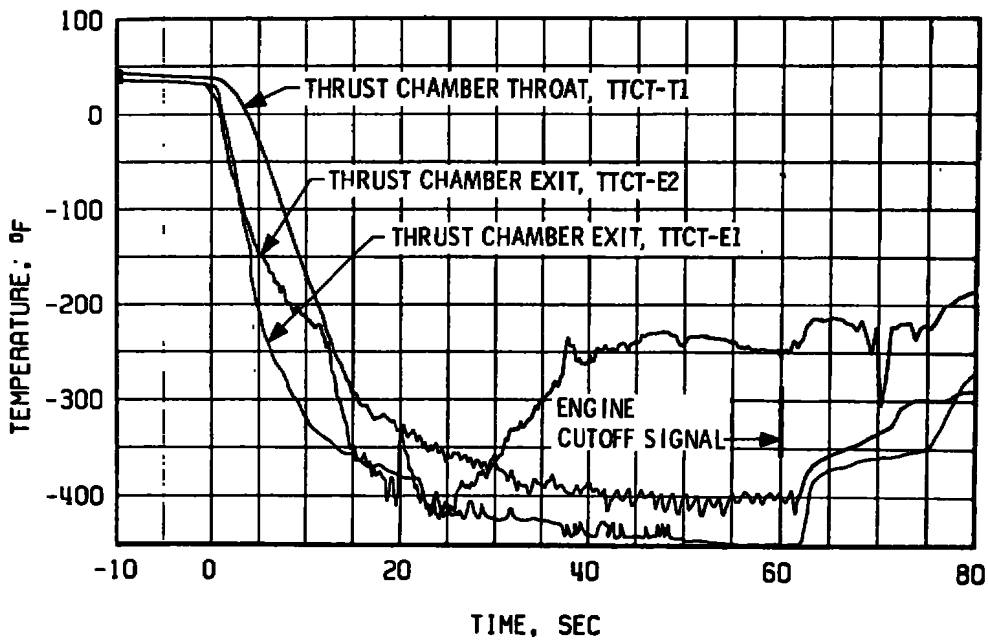


Fig. 32 Thrust Chamber Chilldown, Firing 10C

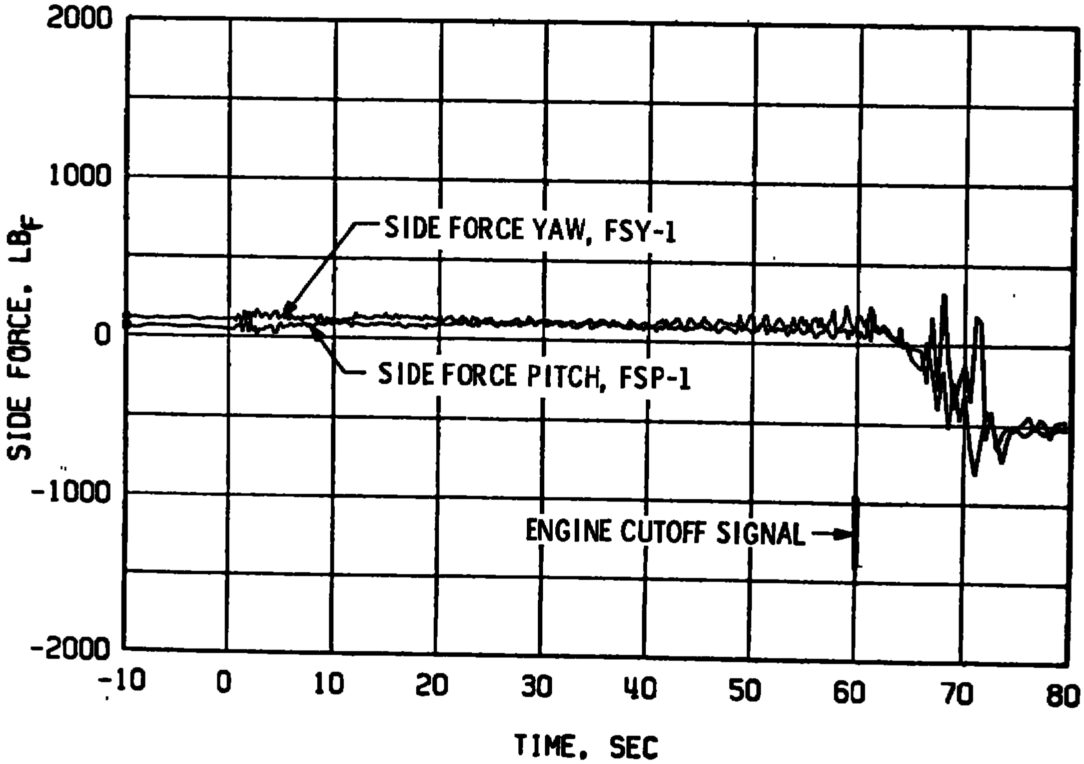


Fig. 33 Engine Side Forces, Firing 10C

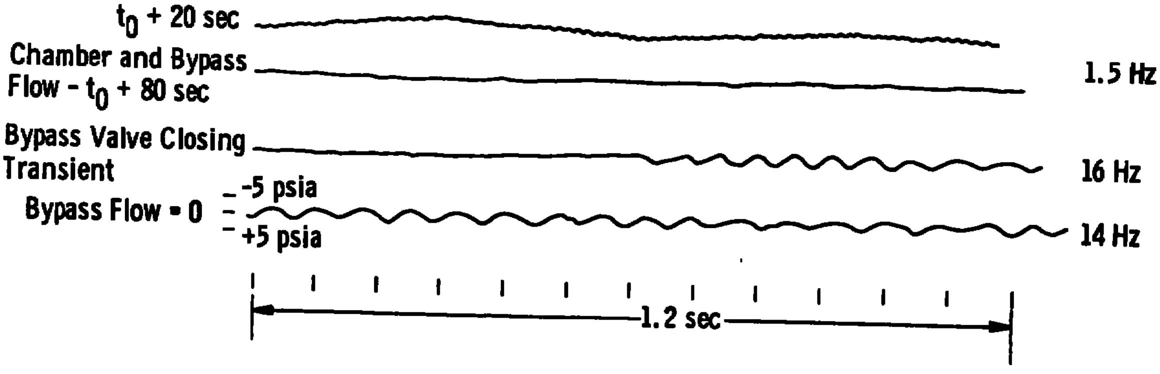


Fig. 34 Chamber Pressure Oscillations, Firing 10A

TABLE I
MAJOR ENGINE COMPONENTS
(EFFECTIVE TEST J4-1902-09)

Part Name	P/N	S/N
Thrust Chamber Body Assembly	99-210620	4094439
Thrust Chamber Injector Assembly	XEOR-937400	4087380
Augmented Spark Igniter Assembly	EWR 113811-21	4901310
Ignition Detector Probe 1	3243-2	016
Ignition Detector Probe 2	3243-1	003X
Fuel Turbopump Assembly	99-461500-31	R004-1A
Oxidizer Turbopump Assembly	99-460430-21	S003-0A
Main Fuel Valve	99-411320x3	8900881
Main Oxidizer Valve	99-411225x4	8900929
Idle-Mode Valve	99-411385	8900867
Thrust Chamber Bypass Valve	99-411180-x1	8900954
Hot Gas Tapoff Valve	99-557824x2	8900847
Propellant Utilization Valve	99-251455x5	8900911
Electrical Control Package	99-503670	4098176
Engine Instrumentation Package	99-704641	4097437
Pneumatic Control Package	99-558330	8900817
Restart Control Assembly	99-503680	4097867
Helium Tank Assembly	NA5-260212-1	0002
Oxidizer Flowmeter	251216	4096874
Fuel Flowmeter	251225	4096875
Fuel Inlet Duct Assembly	409900-11	6631788
Oxidizer Inlet Duct Assembly	409899	4052289
Fuel Pump Discharge Duct	99-411082-7	439
Oxidizer Pump Discharge Duct	99-411082-5	439
Thrust Chamber Bypass Duct	XEOR 934887-3 XEOR 934887-5	J112-1
Fuel Turbine Exhaust Bypass Duct	307879-11	2143580
Hot Gas Tapoff Duct	99-411080-51	7239768
Solid-Propellant Turbine Starters Manifold	99-210921-11	7216433
Heat Exchanger and Oxidizer Turbine Exhaust Duct	307887	2142922
Crossover Duct	307879	2143592
Thrust Chamber Bypass Flowmeter	40SCRF2	1074

TABLE II
SUMMARY OF ENGINE ORIFICES

Orifice Name	Part Number	Diameter, Inches Unless Otherwise Noted	Test Effective	Comments
Oxidizer Turbine Bypass Nozzle	99-210924	1.996	J4-1902-05	---
Film Coolant Venturi	---	1.027 Inlet 0.744 Throat	J4-1902-05	$C_D = 0.97$
Augmented Spark Igniter Oxidizer Supply Line	652050	0.0999	J4-1902-05	---
Augmented Spark Igniter Fuel Supply Line	---	---	J4-1902-05	No Orifice Installed
Film Coolant	EWR 1138	0.581	J4-1902-08	EWR 121099
Thrust Chamber Bypass Line	EWR 113813	1.751	J4-1902-08	EWR 121871

TABLE III
ENGINE MODIFICATIONS
(BETWEEN TESTS J4-1902-09 AND J4-1902-10)

Modification Number	Completion Date	Description of Modification
Test J4-1902-08, 4/2/69		
121886	4/13/69	Installation of Injector with 10th-Row Oxidizer Idle-Mode Compartment
121893	4/14/69	Installation of Thrust Chamber Bypass Duct with Flowmeter
121898	4/12/69	Repair of Thrust Chamber Combustion Zone Tube Damage
121899	4/13/69	Installation of a 1.417-in. Tapoff Valve Stop
Test J4-1902-09, 4/17/69		
121661	4/21/69	Installation of 1.500-in. Thrust Chamber Bypass Orifice
Test J4-1902-10, 4/24/69		

TABLE IV
ENGINE COMPONENT REPLACEMENTS
(BETWEEN TESTS J4-1902-09 AND J4-1902-10)

Replacement	Completion Date	Component Replaced
Test J4-1902-08		
121651	4/13/69	Oxidizer Flowmeter Coil
Test J4-1902-09, 4/17/69		
None		
Test J4-1902-10, 4/24/69		

TABLE V
ENGINE PURGE SEQUENCE

Purge	Requirement	Solid-Propellant Turbine Starter Installed	Air-On	Propellant Drop	Engine Start	Cutoff / Coast Period	Propellant Drop	Restart	Cutoff (Last Firing)
Oxidizer Dome and Idle-Mode Compartment	Nitrogen, 600 ± 25 psia; 100 to 150°F CCP 150 scfm								15 min
Thrust Chamber Jacket, Film Coolant and Turbopump Purges	Helium, 150 ± 25 psia; 100 to 150°F at CCP (125 scfm)		(b) (c)		(a)	15 min (b) (c)		(a)	15 min

(a) Engine-Supplied Oxidizer Turbopump Intermediate Seal Cavity Purge
(b) Any Time Facility Water On
(c) 30 min before Propellant Drop

TABLE VI
SUMMARY OF TEST REQUIREMENTS AND RESULTS

Firing Number	J4-1902-09A		J4-1902-09B		J4-1902-10A		J4-1902-10B		J4-1902-10C	
	Target	Actual	Target	Actual	Target	Actual	Target	Actual	Target	Actual
Firing Date/Time of Day	4/17/69	1847	4/17/69	1818	4/24/69	1140	4/24/69	1258	4/24/69	1416
Pressure Altitude at t_0, ft (Ref. 1)	100,000	74,000	100,000	77,000	100,000	90,500	100,000	103,100	100,000	101,700
Idle-Mode Duration Pre-Main Stage, sec*	75	76.3	75	75.8	125	125.147	100	100.7	60	60.6
Fuel Pump Inlet Pressure at t_0, psia	33 ± 1.0	33.0	30 ± 1.0	30.0	33 ± 1	32.9	30 ± 1	30.1	40 ± 1.0	40.4
Fuel Pump Inlet Temperature at t_0, °F	---	-417.6	---	-418.3	---	-417.6	---	-418.3	---	-416.6
Fuel Tank Bulk Temperature at t_0, °F	-422.4 ±0.4	-422.5	-422.4 ± 0.4	-422.3	-422.0 ± 0.4	-422.4	-422 ±0.4	-422.5	-422 ±0.4	-422.6
Oxidizer Pump Inlet Pressure at t_0, psia	39 ± 1.0	38.7	45 ± 1.0	44.8	39 ± 1.0	38.8	45 ± 1.0	44.6	30 ± 1.0	30.0
Oxidizer Pump Inlet Temperature at t_0, °F	---	-291.7	---	-291.1	---	-291.4	---	-292.3	---	-290.7
Oxidizer Tank Bulk Temperature at t_0, °F	-295.0 ± 0.4	-295.4	-295.0 ± 0.4	-294.3	-295.0 ± 0.4	-294.4	-295.0 ± 0.4	-295.1	-295 ± 0.4	-295.0
Helium Tank Conditions at t_0 — Pressure, psia	3450^{+0}_{-200}	3192	Remains from A	3073	3450^{+0}_{-200}	3125	Remains from A	2924	Remains from B	2816
Helium Tank Conditions at t_0 — Temperature, °F	---	78	---	72	---	93	---	72	---	70
Fuel Injector Temperature at t_0, °F	50 ± 25	58.2	50 ± 25	24.5	50 ± 25	69.7	50 ± 25	13.8	50 ± 25	18.8
Augmented Spark Igniter Ignition Detected, sec (Ref. t_0)*	---	0.508	---	0.450	---	0.570	---	0.440	---	0.739
Propellant Utilization Valve Position at t_0	Null	Null	Null	Null	Null	Null	Null	Null	Null	Null
Thrust Chamber Bypass Valve, Position/Time	Open	Open	Open	Open	Open t_0	Open t_0	Open	Open	Open	Open
					Close t_0 +100	Close t_0 +101.2				

*Data Reduced from Oscillogram

TABLE VII
ENGINE VALVE TIMINGS

Test J4-1902-	Firing	Start: Main Fuel Valve			Start: Idle-Mode Oxidizer Valve			Shutdown: Main Fuel Valve			Shutdown: Idle-Mode Oxidizer Valve		
		Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec	Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec
09	A	0.0	0.050	0.055	0.0	0.118	0.055	76.312	0.070	0.255	76.312	0.065	0.150
	B	0.0	0.050	0.052	0.0	0.120	0.056	75.773	0.070	0.253	75.773	0.065	0.147
	Final Sequence	0.0	0.045	0.060	0.0	0.111	0.045	---	0.070	0.254	---	0.062	0.104
10	A	0.0	0.047	0.055	0.0	0.115	0.056	125.147	0.072	0.257	125.147	0.066	0.143
	B	0.0	0.049	0.055	0.0	0.122	0.052	100.72	0.070	0.258	100.72	0.066	0.150
	C	0.0	0.053	0.056	0.0	0.120	0.044	60.58	0.075	0.255	60.58	0.070	0.148
	Final Sequence	0.0	0.045	0.070	0.0	0.120	0.045	---	0.070	0.257	---	0.065	0.108

Notes:
1. All valve signal times are referenced to t_0.
2. Valve delay time is the time required for initial valve movement after the valve open or closed solenoid has been energized.
3. Final sequence check is conducted without propellants and within 12 hr before testing.
4. Data are reduced from oscillogram.

TABLE VIII
ENGINE IDLE-MODE PERFORMANCE

Test Number, J4-1902-	09A					09B				
Time Slice, sec*	40	50	60	70	74.5	40	50	60	70	74.6
Fuel Pump Inlet Pressure, psia	32.9	32.8	32.7	32.6	32.6	30.2	30.3	30.4	30.4	30.5
Oxidizer Pump Inlet Pressure, psia	38.4	38.9	38.7	38.4	39.3	44.4	44.8	44.4	45.0	44.8
Chamber Pressure, psia	19.2	19.9	19.3	19.1	18.5	19.2	19.2	18.8	18.6	17.1
Propellant Mixture Ratio, O/F	1.75	1.60	1.78	1.72	1.74	1.82	1.88	1.75	2.13	1.74
Characteristic Velocity, C*, ft/sec	3260	3119	3103	3046	3056	2915	2889	2768	2865	2464
Characteristic Velocity Efficiency, C^*_{eff}, percent	42.3	40.0	40.2	39.6	39.7	37.7	37.2	35.9	36.4	32.0
Vacuum-Corrected Thrust, F_{vac}, lb_f	3937	4071	3988	3923	4004	3949	3939	3870	3844	3511
Vacuum-Corrected Coefficient of Thrust, CF_{vac}	1.75	1.75	1.75	1.75	1.75	1.75	1.78	1.75	1.75	1.75
Vacuum-Corrected Specific Impulse, $(I_{sp})_{vac}$, lb_f-sec/lb_m	177.4	169.3	169.1	165.7	168.3	158.0	157.7	150.7	157.2	134.1
Total Oxidizer Flow Rate, $\dot{W}_o$, lb_m/sec	14.1	14.8	15.0	15.0	15.3	16.0	16.3	16.3	16.8	16.5
Total Fuel Flow Rate, $\dot{W}_f$, lb_m/sec	8.07	9.24	8.45	8.71	8.80	8.83	8.68	9.35	7.85	9.65
Idle-Mode Fuel Flow Rate, $(\dot{W}_f)_{imc}$, lb_m/sec	1.00	1.15	1.05	1.08	1.09	1.09	1.00	1.18	0.97	1.10
Idle-Mode Mixture Ratio, $(O/F)_{imc}$	14.1	12.9	14.3	13.9	14.0	14.7	15.1	14.1	17.1	14.1
Fuel Injection Density, $\rho_{f_{inj}}$, lb_m/ft^3	0.120	0.189	0.167	0.173	0.145	0.153	0.160	0.168	0.138	0.193

Test Number, J4-1902-	10A									
Time Slice, sec*	40	50	60	70	80	90	99.5	110	120	124.5
Fuel Pump Inlet Pressure, psia	32.6	32.6	32.4	32.3	32.4	32.4	32.5	32.6	32.8	32.7
Oxidizer Pump Inlet Pressure, psia	38.9	39.0	38.9	38.9	38.9	38.9	38.9	38.9	38.0	38.9
Chamber Pressure, psia	17.9	18.1	17.8	17.7	17.7	17.3	17.0	16.1	16.1	16.0
Propellant Mixture Ratio, O/F	1.74	1.73	1.81	1.86	1.97	1.88	2.00	2.63	2.76	2.88
Characteristic Velocity, C*, ft/sec	2970	2890	2865	2859	2897	2772	2824	2943	2920	2955
Characteristic Velocity Efficiency, C^*_{eff}, percent	38.8	37.6	37.0	36.8	37.1	35.7	36.1	38.8	38.6	37.0
Vacuum-Corrected Thrust, F_{vac}, lb_f	3672	3707	3658	3634	3654	3554	3510	3382	3375	3367
Vacuum-Corrected Coefficient of Thrust, CF_{vac}	1.75	1.75	1.75	1.75	1.76	1.76	1.76	1.79	1.79	1.79
Vacuum-Corrected Specific Impulse, $(I_{sp})_{vac}$, lb_f-sec/lb_m	161.7	157.3	156.1	155.9	158.6	151.3	154.6	164.0	162.6	164.8
Total Oxidizer Flow Rate, $\dot{W}_o$, lb_m/sec	14.4	14.9	15.1	15.2	15.3	15.3	15.1	15.2	15.2	15.1
Total Fuel Flow Rate, $\dot{W}_f$, lb_m/sec	8.30	8.62	8.34	8.14	7.77	8.21	7.57	5.38	5.52	5.29
Idle-Mode Fuel Flow Rate, $(\dot{W}_f)_{imc}$, lb_m/sec	1.03	1.07	1.03	1.01	0.96	1.02	0.94	0.87	0.68	0.66
Idle-Mode Mixture Ratio, $(O/F)_{imc}$	14.0	13.9	14.7	15.0	15.9	15.0	16.1	22.7	22.4	22.9
Fuel Injection Density, $\rho_{f_{inj}}$, lb_m/ft^3	0.130	0.139	0.166	0.143	0.115	0.152	0.141	0.057	0.061	0.065

Test Number, J4-1902-	10B							10C		
Time Slice, sec*	40	50	60	70	80	90	99.5	40	50	59.5
Fuel Pump Inlet Pressure, psia	30.2	30.0	29.9	29.8	29.7	29.8	29.8	39.9	39.8	39.7
Oxidizer Pump Inlet Pressure, psia	43.4	43.4	41.2	43.1	43.0	42.8	42.7	30.8	30.7	30.6
Chamber Pressure, psia	17.6	17.5	17.4	17.5	17.0	17.3	17.7	18.0	18.1	18.0
Propellant Mixture Ratio, O/F	2.05	2.07	2.11	2.11	1.89	1.84	2.24	0.96	1.02	1.07
Characteristic Velocity, C*, ft/sec	2873	2798	2749	2715	2558	2575	2814	3087	2892	2954
Characteristic Velocity Efficiency, C^*_{eff}, percent	38.7	35.6	35.0	34.8	32.9	33.2	35.6	44.8	42.7	41.6
Vacuum-Corrected Thrust, F_{vac}, lb_f	3629	3604	3601	3618	3495	3549	3666	3681	3532	3645
Vacuum-Corrected Coefficient of Thrust, CF_{vac}	1.76	1.76	1.77	1.77	1.76	1.76	1.77	1.75	1.66	1.73
Vacuum-Corrected Specific Impulse, $(I_{sp})_{vac}$, lb_f-sec/lb_m	157.5	153.3	160.8	140.1	139.7	140.5	154.9	167.4	154.7	159.0
Total Oxidizer Flow Rate, $\dot{W}_o$, lb_m/sec	15.5	15.8	16.2	16.4	16.4	16.4	16.4	10.6	11.5	11.9
Total Fuel Flow Rate, $\dot{W}_f$, lb_m/sec	7.58	7.67	7.68	7.74	8.64	8.89	7.30	11.4	11.3	11.1
Idle-Mode Fuel Flow Rate, $(\dot{W}_f)_{imc}$, lb_m/sec	0.94	0.95	0.95	0.98	1.07	1.10	0.91	1.41	1.40	1.38
Idle-Mode Mixture Ratio, $(O/F)_{imc}$	16.5	16.6	17.1	17.1	15.3	14.9	18.0	7.52	8.21	8.62
Fuel Injection Density, $\rho_{f_{inj}}$, lb_m/ft^3	0.179	0.114	0.122	0.125	0.123	0.110	0.108	0.263	0.280	0.282

*Data averaged for ±0.5 sec at the indicated times

APPENDIX III
INSTRUMENTATION

The instrumentation for AEDC tests J4-1902-09 and J4-1902-10 is tabulated in Table III-1. The location of selected major engine instrumentation is shown in Fig. III-1.

TABLE III-1
INSTRUMENTATION LIST FOR IDLE-MODE OPERATION

AEDC Code	Parameter	Tap No.	Range	Digital Data System	Magnetic Tape	Oscillograph	Strip Chart	Event Recorder	X-Y Plotter
	Current		**amp**						
ICC	Control		0 to 30	x					
IIC	Ignition		0 to 30	x					
	Event								
EASIS-1	Augmented Spark Igniter Spark 1		On/Off					x	
EASIS-2	Augmented Spark Igniter Spark 2								
EECL	Engine Cutoff Lockin			x		x			
EECO	Engine Cutoff Signal			x		x			
EER	Engine Ready Signal								
EES	Engine Start Command			x		x			
EESCO	Programmed Duration Cutoff								
EFBVO	Fuel Bleed Valve Open Limit								
EFPVC	Fuel Prevalve Closed Limit			x					
EFPVO	Fuel Prevalve Open Limit			x					
EHCS	Helium Control Solenoid Energized			x	x	x			
EID	Ignition Detected			x		x			
EIDA-1	Ignition Detect Amplifier 1								
EIDA-2	Ignition Detect Amplifier 2								
EIMCS	Idle-Mode Control Solenoid Energized			x		x			
EIMVC	Idle-Mode Valve Closed Limit								
EIMVO	Idle-Mode Valve Open Limit								
EMFVC	Main Fuel Valve Closed Limit								
EMFVO	Main Fuel Valve Open Limit								
EMOVC	Main Oxidizer Valve Closed Limit								
EMOVO	Main Oxidizer Valve Open Limit								
EOBVO	Oxidizer Bleed Valve Open Limit								
EOCO	Observer Cutoff Signal								
EOPVC	Oxidizer Prevalve Closed Limit			x					
EOPVO	Oxidizer Prevalve Open Limit			x					
ERASIS-1	Augmented Spark Igniter Spark Rate 1					x			
ERASIS-2	Augmented Spark Igniter Spark Rate 2					x			
ESTCO	Start OK Timer Cutoff Signal								
ETCBC	Thrust Chamber Bypass Valve Closed								
ETCBO	Thrust Chamber Bypass Valve Open								
EVSC-1	Vibration Safety Counts 1					x			
EVSC-2	Vibration Safety Counts 2					x			
EVSC-3	Vibration Safety Counts 3					x			

TABLE III-1 (Continued)

AEDC Code	Parameter	Tap No.	Range	Digital Data System	Magnetic Tape	Oscillograph	Strip Chart	Event Recorder	X-Y Plotter
	Flows		gpm						
QF-1	Engine Fuel	PFF	0 to 11,000	x					
QF-2	Engine Fuel	PFFa	0 to 11,000	x	x	x			
QF-3	Engine Fuel	PFF	0 to 11,000			x			
QFBD	Fuel Bypass Duct		0 to 500	x	x	x			
QO-1	Engine Oxidizer	POF	0 to 3600	x					
QO-2	Engine Oxidizer	POFa	0 to 3600	x	x	x			
QO-3	Engine Oxidizer	POF	0 to 3600			x			
	Forces		lb_f						
FSP-1	Side Load (Pitch)		±20,000	x		x			
FSY-1	Side Load (Yaw)		±20,000	x		x			
	Position		Percent Open						
LFBT	Thrust Chamber Bypass Valve		0 to 100	x		x			
LFVT	Main Fuel Valve		0 to 100						
LIMT	Idle-Mode/Augmented Spark Igniter Oxidizer Valve		0 to 100						
LOVT	Main Oxidizer Valve		0 to 100						
LPUTOP	Propellant Utilization Valve		5 v				x		
LTVT	Hot Gas Tapoff Valve		0 to 100						
	Pressure		psia						
PA-1	Test Cell		0 to 0.5						
PA-2	Test Cell		0 to 1.0						
PA-3	Test Cell		0 to 5.0			x	x		
PC-1P	Thrust Chamber	CG1	0 to 1500						
PC-2P	Thrust Chamber	CG1a-1	0 to 1500			x	x		
PC-2PL	Thrust Chamber	CG1a-1	0 to 50			x	x		
PCASI-L	Augmented Spark Igniter Chamber	IG1	0 to 50			x			
PCW-1	Thrust Chamber Wall		0 to 1						
PCW-2	Thrust Chamber Wall		0 to 1						
PCW-3	Thrust Chamber Wall		0 to 1						
PCW-4	Thrust Chamber Wall		0 to 1						
PCW-5	Thrust Chamber Wall		0 to 1						
PFBM	Thrust Chamber Bypass Manifold	CF3	0 to 1500						
PFCO-L	Film Coolant Orifice	CF4	0 to 50						
PFCVI	Film Coolant Venturi Inlet	CF7	0 to 2000						
PFCVI-L	Film Coolant Venturi Inlet	CF7	0 to 50						
PFCVT	Film Coolant Venturi Throat	CF6	0 to 2000						
PFCVT-L	Film Coolant Venturi Throat	CF6	0 to 50						
PFJ-1	Fuel Injection	CF2	0 to 500			x			
PFJ-1L	Fuel Injection	CF2	0 to 50						x
PFMI	Fuel Jacket Manifold Inlet	CF1	0 to 2000						
PFMI-L	Fuel Jacket Manifold Inlet	CF1	0 to 50						
PFPBC	Fuel Pump Balance Piston Cavity	PF5	0 to 2000			x	x		
PFPBS	Fuel Pump Balance Piston Sump	PF4	0 to 1000			x	x		

TABLE III-1 (Continued)

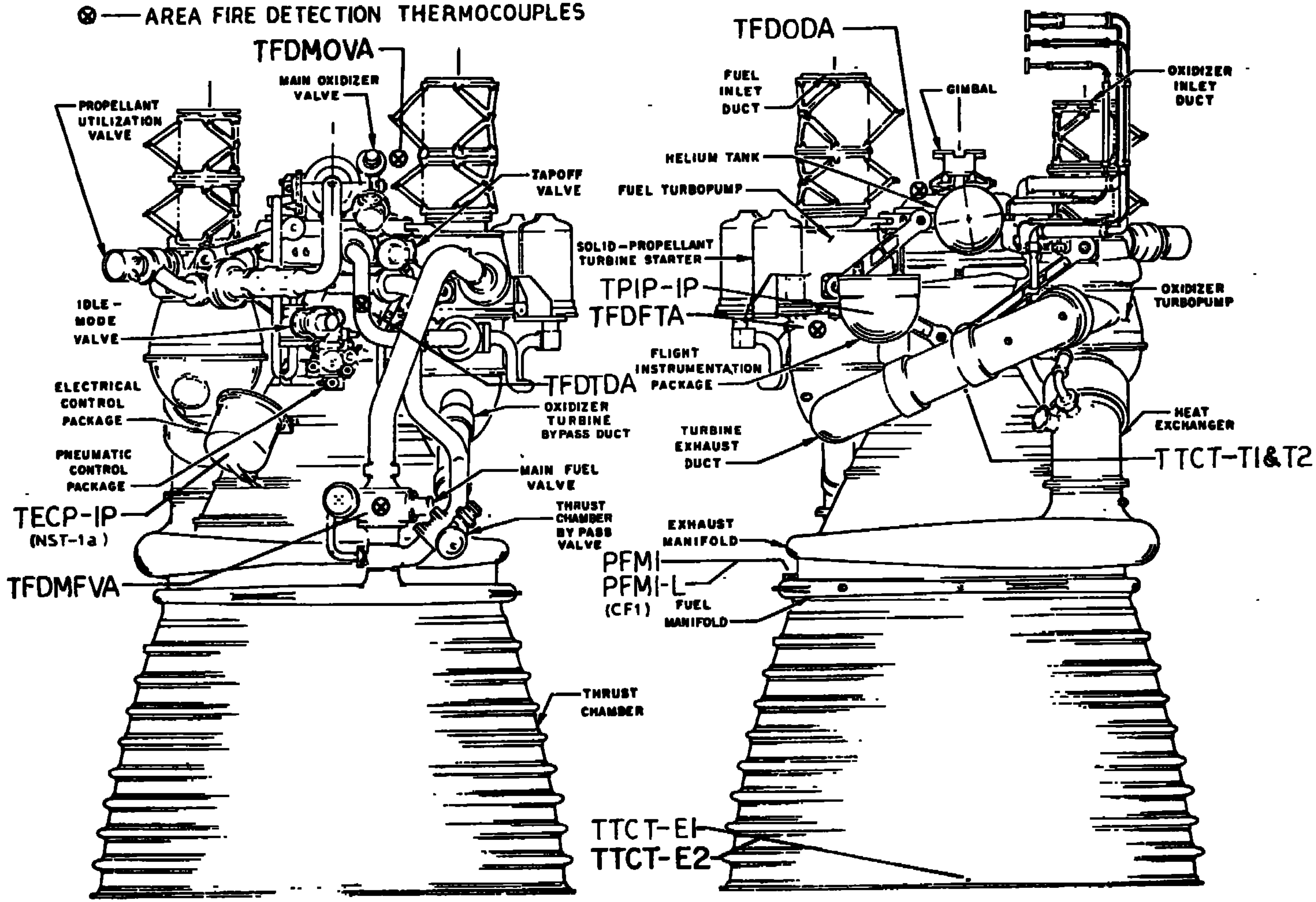
AEDC Code	Parameter	Tap No.	Range	Digital Data System	Magnetic Tape	Oscillo-graph	Strip Chart	Event Recorder	X-Y Plotter
	Pressure		psia						
PFPD-1L	Fuel Pump Discharge	PF3	0 to 50	x					
PFPD-1P	Fuel Pump Discharge	PF3	0 to 2500				x		
PFPD-2	Fuel Pump Discharge	PF2	0 to 500		x	x			
PFPI-1	Fuel Pump Inlet	PF1	0 to 100				x		x
PFPI-2	Fuel Pump Inlet		0 to 100						x
PFPI-3	Fuel Pump Inlet	PF1A	0 to 100		x	x			
PFPRB	Fuel Pump Rear Bearing Coolant	PF7	0 to 1000				x		
PFPS	Fuel Pump Interstage	PF6	0 to 200			x	x		
PFPSI	Fuel Pump Shroud Inlet		0 to 2500				x		
PFTI-1P	Fuel Turbine Inlet	TG1	0 to 1000			x			
PFTO	Fuel Turbine Outlet	TG2	0 to 200						
PFTSC	Fuel Turbine Seal Cavity	TG10	0 to 500						
PFUT	Fuel Ullage Tank		0 to 100						
PHEA	Helium Accumulator	NN3	0 to 750						
PHES	Helium Supply		0 to 5000						
PHET-1P	Helium Tank	NN1-1	0 to 5000						x
PHET-2P	Helium Tank	NN1-3	0 to 5000						
PHRO-1P	Helium Regulator Outlet	NN2	0 to 750						
PNODP	Oxidizer Dome Purge at Customer Connect Panel		0 to 750						
POASIJ	Augmented Spark Igniter Oxidizer Injection	I03	0 to 1500			x			
POASIJ-L	Augmented Spark Igniter Oxidizer Injection	I03	0 to 50						
POIML	Oxidizer Idle-Mode Line	P010	0 to 2000						
POIML-L	Oxidizer Idle-Mode Line	P010	0 to 50						
POJ-1	Oxidizer Injection	C03	0 to 500						
POJ-2	Oxidizer Injection	C03a	0 to 1500			x			
POPBC	Oxidizer Pump Bearing Coolant	P07	0 to 500				x		
POPD-1L	Oxidizer Pump Discharge	P03	0 to 50						
POPD-1P	Oxidizer Pump Discharge	P03	0 to 2500						
POPD-2	Oxidizer Pump Discharge	P02	0 to 500		x	x			
POPI-1	Oxidizer Pump Inlet	P01	0 to 100						x
POPI-2	Oxidizer Pump Inlet		0 to 100						x
POPI-3	Oxidizer Pump Inlet	P01a	0 to 100		x	x			
POPSC	Oxidizer Pump Primary Seal Cavity	P06	0 to 50						
POTI-1P	Oxidizer Turbine Inlet	TG3	0 to 200						
POTO-1P	Oxidizer Turbine Outlet	TG4	0 to 100						
POUT	Oxidizer Ullage Tank		0 to 100						
PPTD	Photocon Cooling Water (Downstream)		0 to 100						
PPTU	Photocon Cooling Water (Upstream)		0 to 100						
PPUVI	Propellant Utilization Valve Inlet	P08	0 to 2000						
PPUVO	Propellant Utilization Valve Outlet	P09	0 to 1000						

TABLE III-1 (Continued)

AEDC Code	Parameter	Tap No.	Range	Digital Data System	Magnetic Tape	Oscillo-graph	Strip Chart	Event Recorder	X-Y Plotter
	Pressure		**psia**						
PTCFJP	Thrust Chamber Fuel Jacket Purge		0 to 200	x					
PTEM	Turbine Exhaust Manifold	TG5	0 to 50						
PTM-3	Tapoff Manifold	GGT2	0 to 1500						
PTM-L	Tapoff Manifold	GG2	0 to 200			x			
	Speeds		**rpm**						
NFP-1	Fuel Pump	PFV	0 to 33,000		x				
NFP-2	Fuel Pump	PFV	0 to 33,000	x		x			
NFP-3	Fuel Pump	PFV	0 to 33,000			x			
NOP-1	Oxidizer Pump	POV	0 to 12,000		x				
NOP-2	Oxidizer Pump	POV	0 to 12,000	x		x			
NOP-3	Oxidizer Pump	POV	0 to 12,000			x			
	Temperatures		**°F**						
TA-1	Test Cell North		-50 to 800	x					
TA-2	Test Cell East		-50 to 800						
TA-3	Test Cell South		-50 to 800						
TA-4	Test Cell West		-50 to 800						
TECP-1P	Electrical Control Assembly	NST1a	-300 to 200						
TFASIJ	Augmented Spark Igniter Fuel Injection	IFT2	-425 to 100			x			
TFBM	Fuel Bypass Manifold	GG2b	-425 to 100						
TFCO	Film Coolant Orifice	IFT1	-425 to -375						
TFD-Avg	Fire Detection Average		0 to 1000				x		
TFDFTA	Fire Detect Fuel Turbine Manifold Area		0 to 500						
TFDMFVA	Fire Detect Main Fuel Valve Area		0 to 500						
TFDMOVA	Fire Detect Main Oxidizer Valve Area		0 to 500						
TFDODA	Fire Detect Oxidizer Dome Area		0 to 500						
TFDTDA	Fire Detect Tapoff Duct Area		0 to 500						
TFJ-1P	Fuel Injection	CFT2	-425 to -390				x		
TFJ-2P	Fuel Injection	CFT2a	-425 to 100			x	x		
TFPBS	Fuel Pump Balance Piston Sump	PFT4	-425 to 100				x		
TFPD-1P	Fuel Pump Discharge	PFT1	-425 to -390		x				
TFPD-2P	Fuel Pump Discharge	PFT1	-425 to 100						
TFPI-1	Fuel Pump Inlet	KFT2	-425 to -400						x
TFPI-2	Fuel Pump Inlet	KFT2a	-425 to 100						x
TFPRS-1	Fuel Pump Rear Support		-400 to 1800						
TFPRS-2	Fuel Pump Rear Support		-400 to 1800						
TFPRS-3	Fuel Pump Rear Support		-400 to 1800						
TFRT-1	Fuel Run Tank		-425 to -400						
TFRT-3	Fuel Run Tank		-425 to -400						
TFTI-3	Fuel Turbine Inlet	TGT1	-300 to 2400				x		
THET-1P	Helium Tank	NNT1	-200 to 300						x
TMFVS-1	Main Fuel Valve Skin (Outer Wall)		-425 to 100				x		

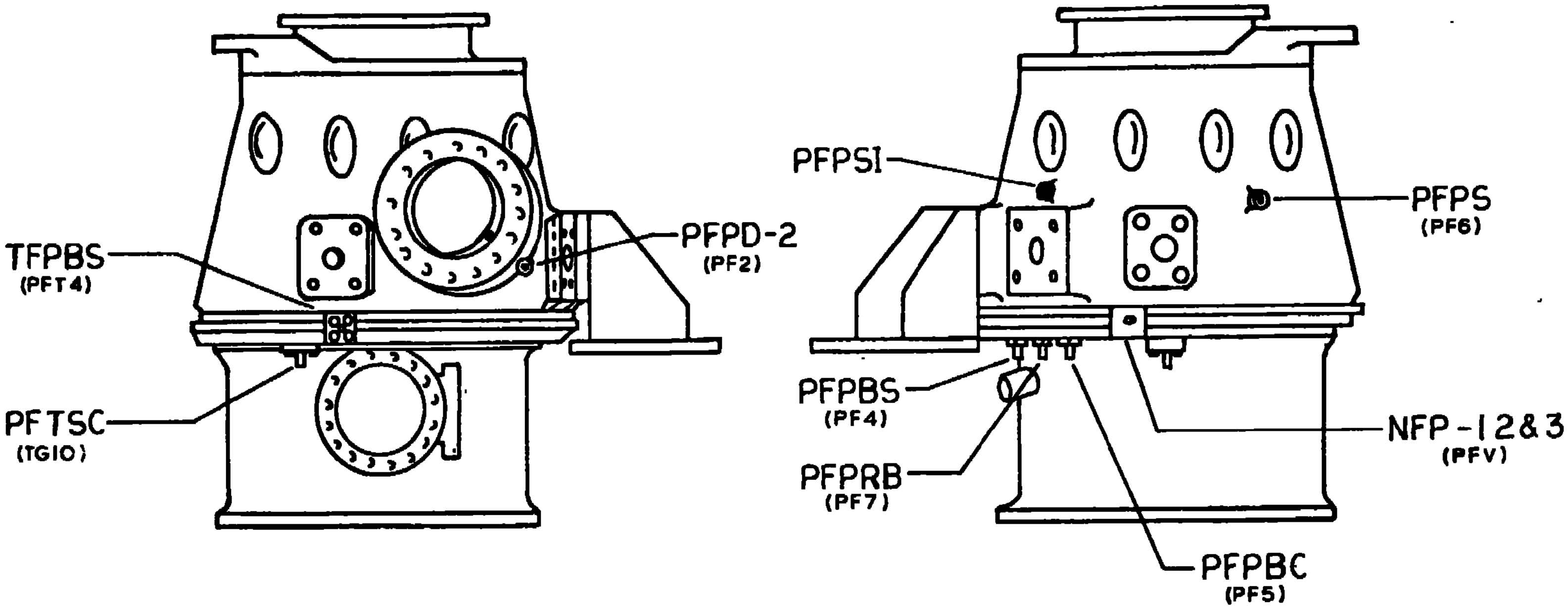
TABLE III-1 (Concluded)

AEDC Code	Parameter	Tap No.	Range	Digital Data System	Magnetic Tape	Oscillo-graph	Strip Chart	Event Recorder	X-Y Plotter
	Temperatures		°F						
TMFVS-2	Main Fuel Valve Skin (Inner Wall)		-425 to 100	x			x		
TNODP	Oxidizer Dome Purge at Customer Connect Panel		-250 to 200						
TOIML	Oxidizer Idle-Mode Line	POT5	-300 to 100						
TOJ	Oxidizer Injection	COT1	-300 to 1200			x			
TOPBC	Oxidizer Pump Bearing Coolant	POT4	-300 to 100				x		
TOPD-1P	Oxidizer Pump Discharge	POT3	-300 to -250						
TOPD-2P	Oxidizer Pump Discharge	POT3	-300 to 100						
TOPI-1	Oxidizer Pump Inlet	KOT2	-310 to -250						x
TOPI-2	Oxidizer Pump Inlet	KOT2a	-310 to 100						x
TORT-1	Oxidizer Run Tank		-300 to -285						
TORT-3	Oxidizer Run Tank		-300 to -285						
TOTI-1P	Oxidizer Turbine Inlet	TGT3A	0 to 1200						
TOTM-1	Oxidizer Turbine Manifold		-300 to 1000						
TOTM-2	Oxidizer Turbine Manifold		-300 to 1000						
TOTO-1P	Oxidizer Turbine Outlet	TGT4	0 to 1000						
TPIP-1P	Instrumentation Package		-300 to 200						
TPTU	Photocon Cooling Water (Upstream)		0 to 200						
TTCIS-1	Thrust Chamber Internal Skin		-300 to 1500				x		
TTCIS-2	Thrust Chamber Internal Skin		-300 to 1500				x		
TTCIS-3	Thrust Chamber Internal Skin		-300 to 1500						
TTCP	Thrust Chamber Purge		-250 to 200						
TTCT-E1	Thrust Chamber Tube (Exit)		-425 to 500						
TTCT-E2	Thrust Chamber Tube (Exit)		-425 to 500						
TTCT-T1	Thrust Chamber Tube (Throat)		-425 to 500				x		
TTCT-T2	Thrust Chamber Tube (Throat)		-425 to 500						
TTM	Hotgas Tapoff Manifold		0 to 2000			x	x		
	Vibrations		g's, peak						
UFPR	Fuel Pump Radial	PZA-1	450		x				
UFTR	Fuel Turbine Radial	TZA	450						
UOPR	Oxidizer Pump Radial	PZA-2	300						
UTCD-1	Thrust Chamber Dome	FZA-1	100			x			
UTCD-2	Thrust Chamber Dome	FZA-2	100			x			
UTCD-3	Thrust Chamber Dome	FZA-3	100			x			
UTCT-1	Thrust Chamber Throat		300						
UTCT-2	Thrust Chamber Throat		300						
	Voltage		V						
VCB	Control Bus		0 to 36	x					
VIB	Ignition Bus		0 to 36						
VIDA-1	Ignition Detect Amplifier		9 to 16						
VIDA-2	Ignition Detect Amplifier		9 to 16						
VPUVEP	Propellant Utilization Valve Telemetry Potentiometer Excitation		0 to 5						



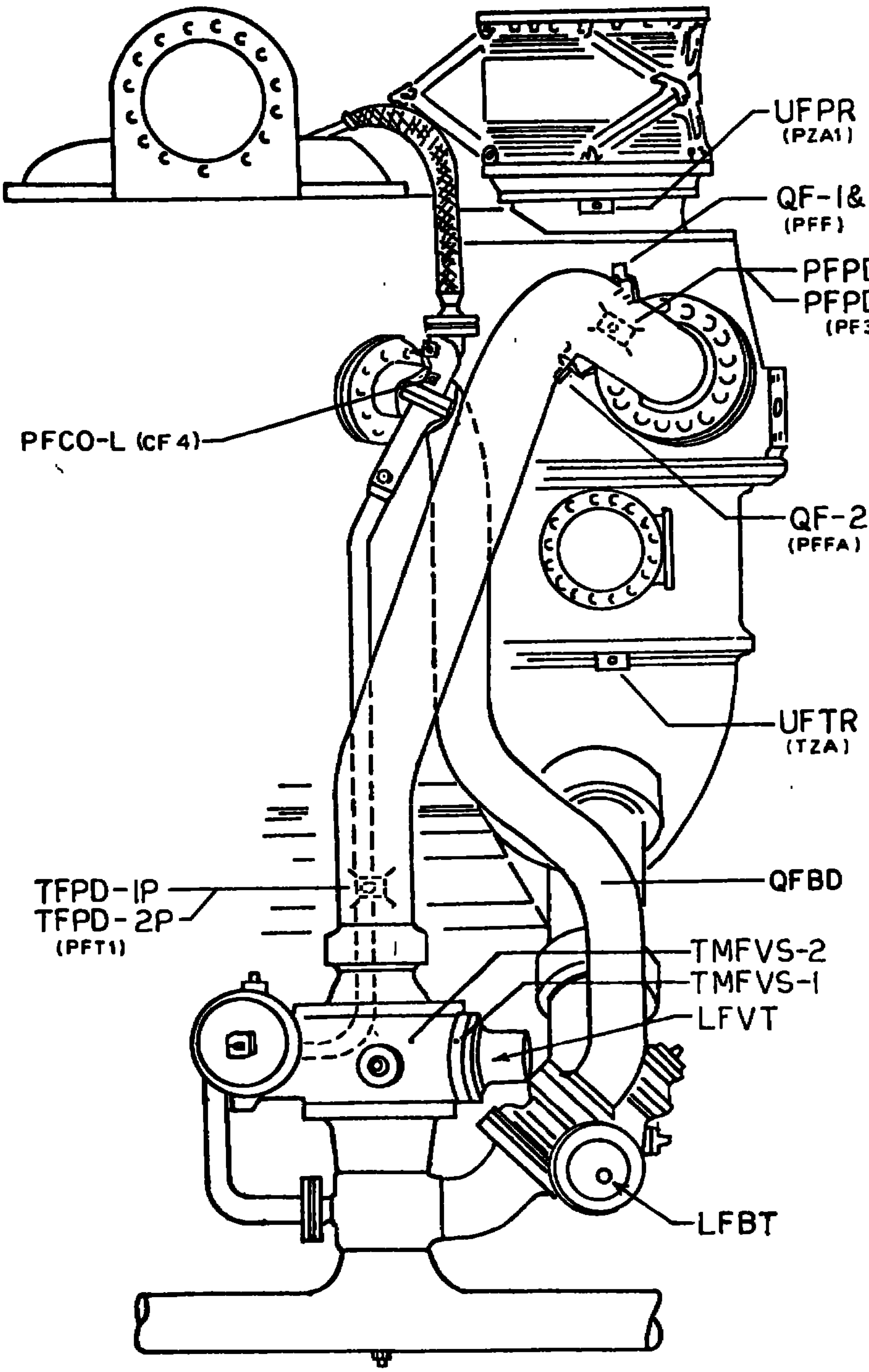
a. General Arrangement

Fig. III-1 Selected Sensor Locations



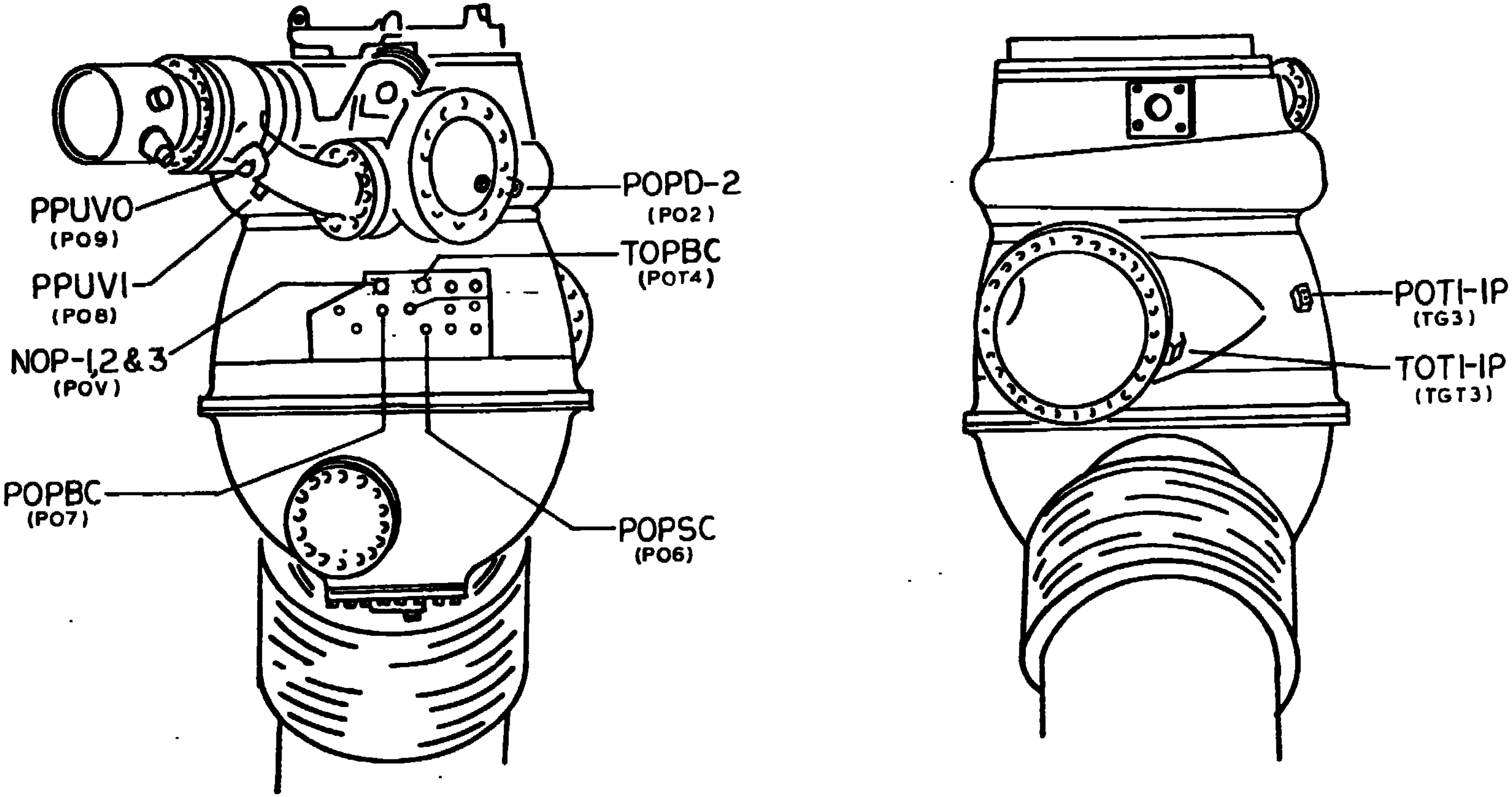
b. Fuel Turbopump Sensor Locations

Fig. III-1 Continued

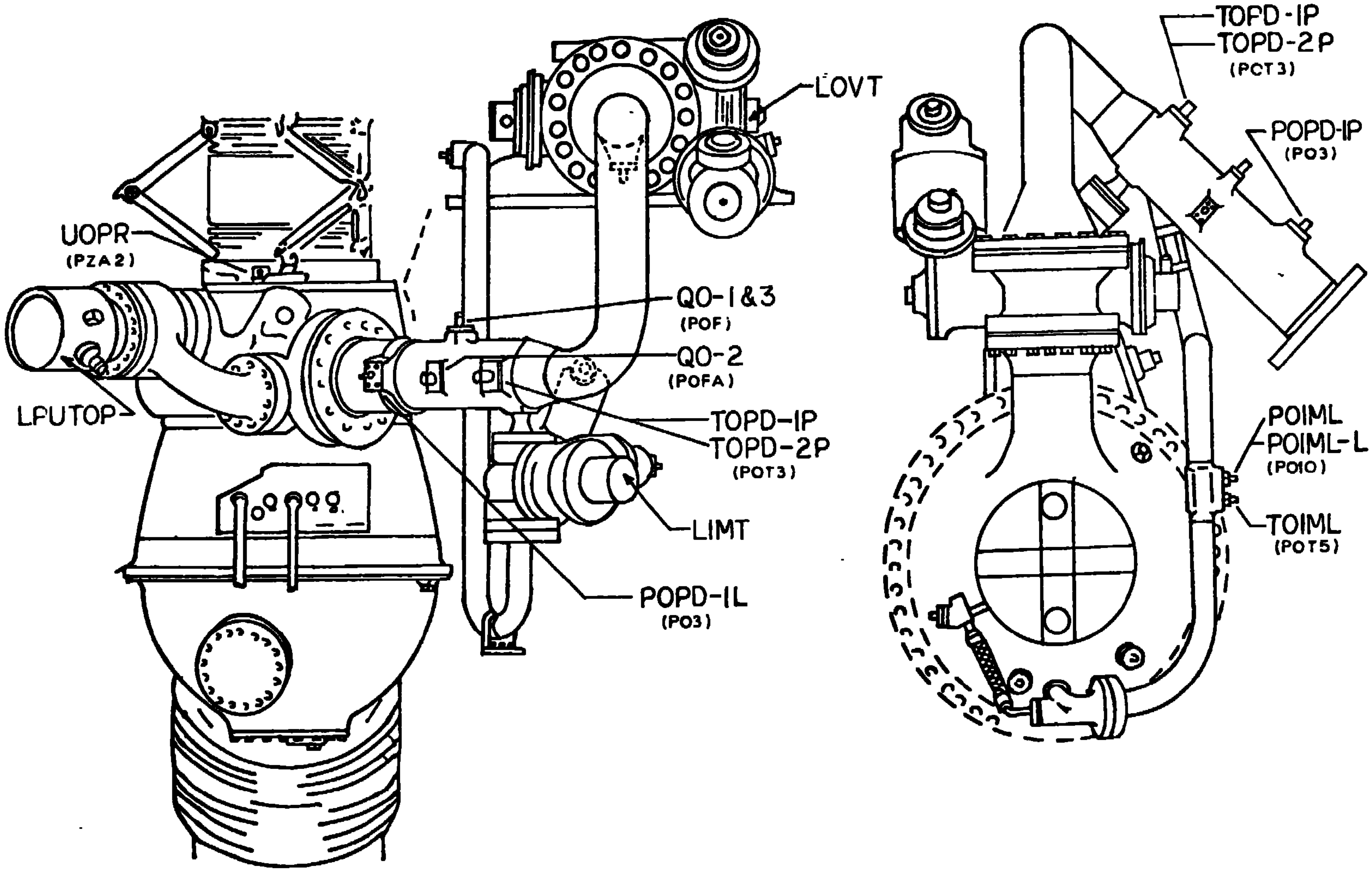


c. Fuel System Sensor Locations

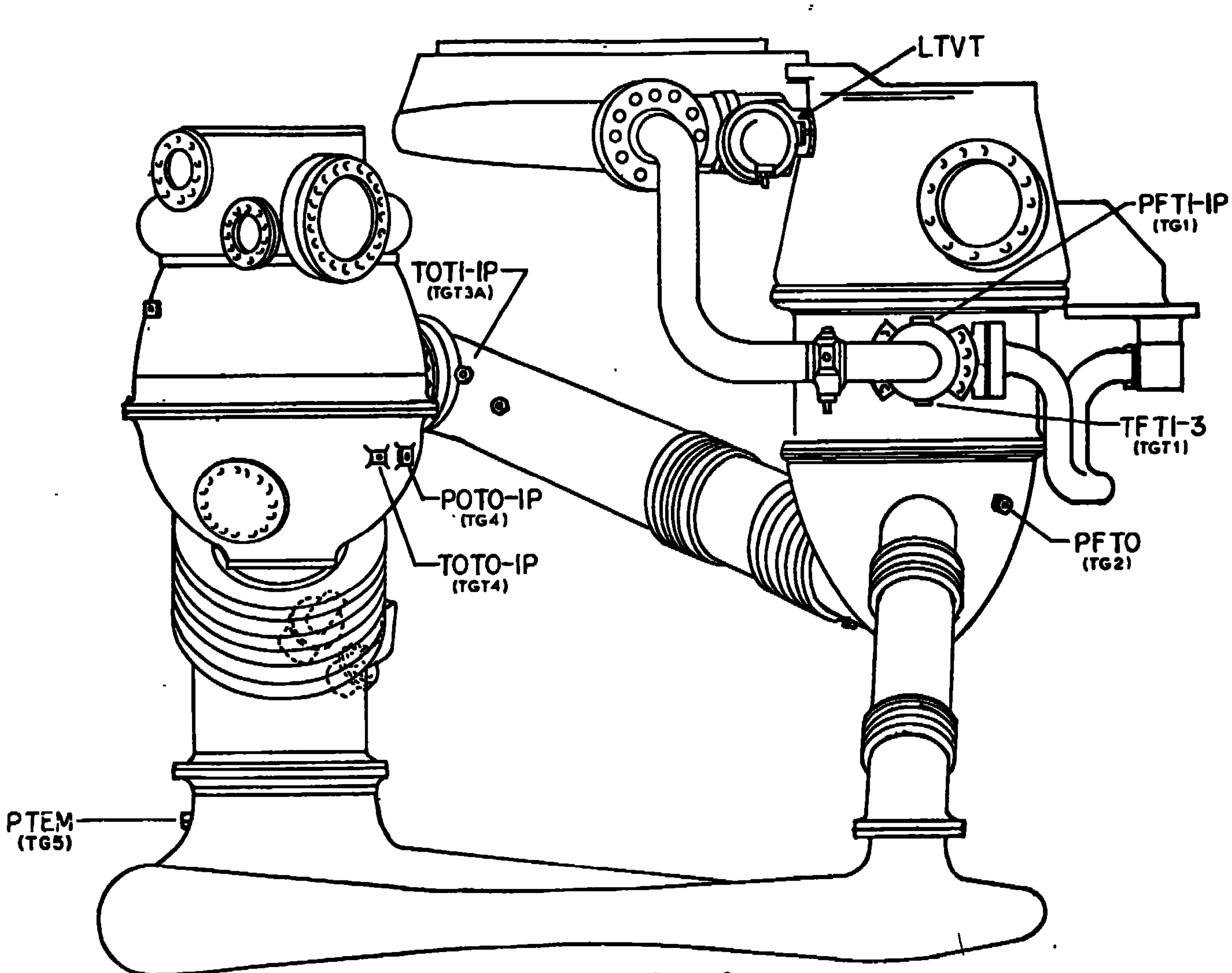
Fig. III-1 Continued



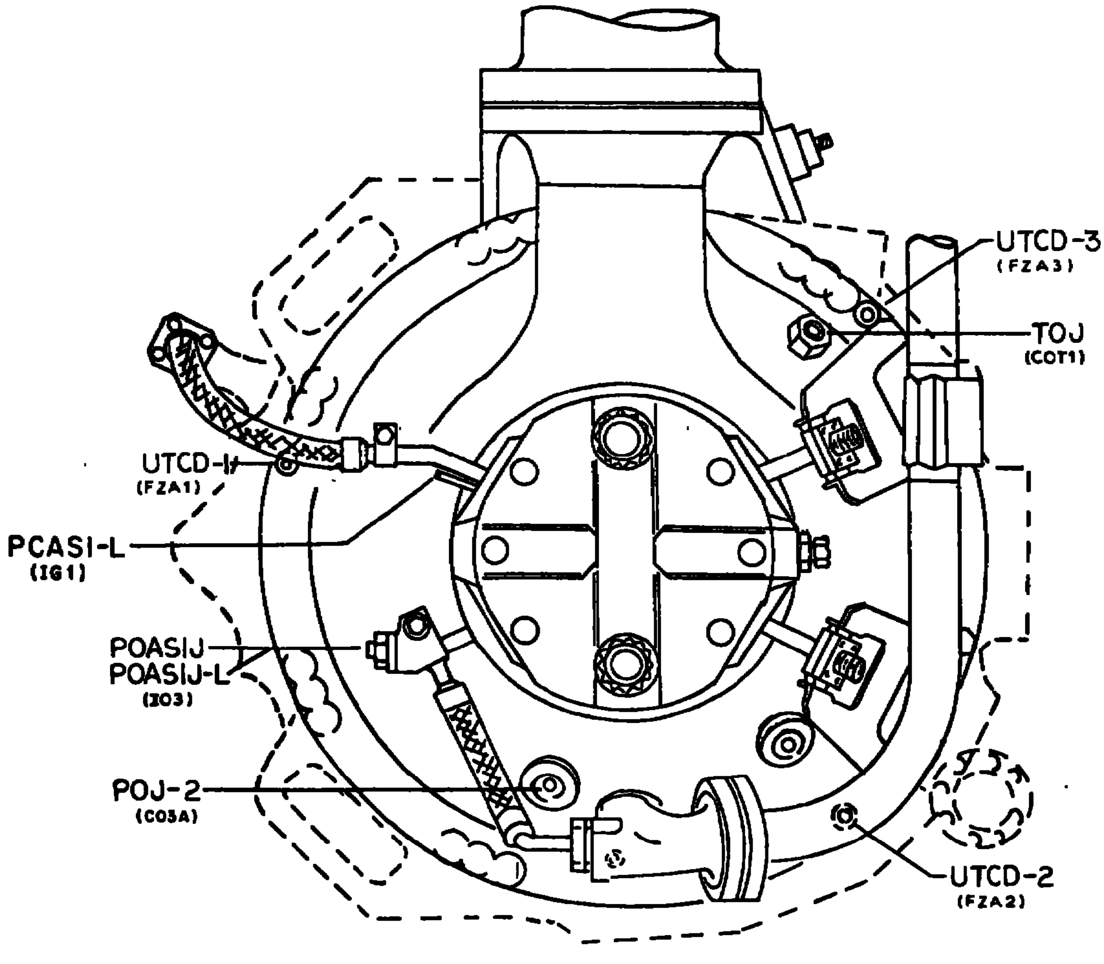
d. Oxidizer Turbopump Sensor Locations
Fig. III-1 Continued



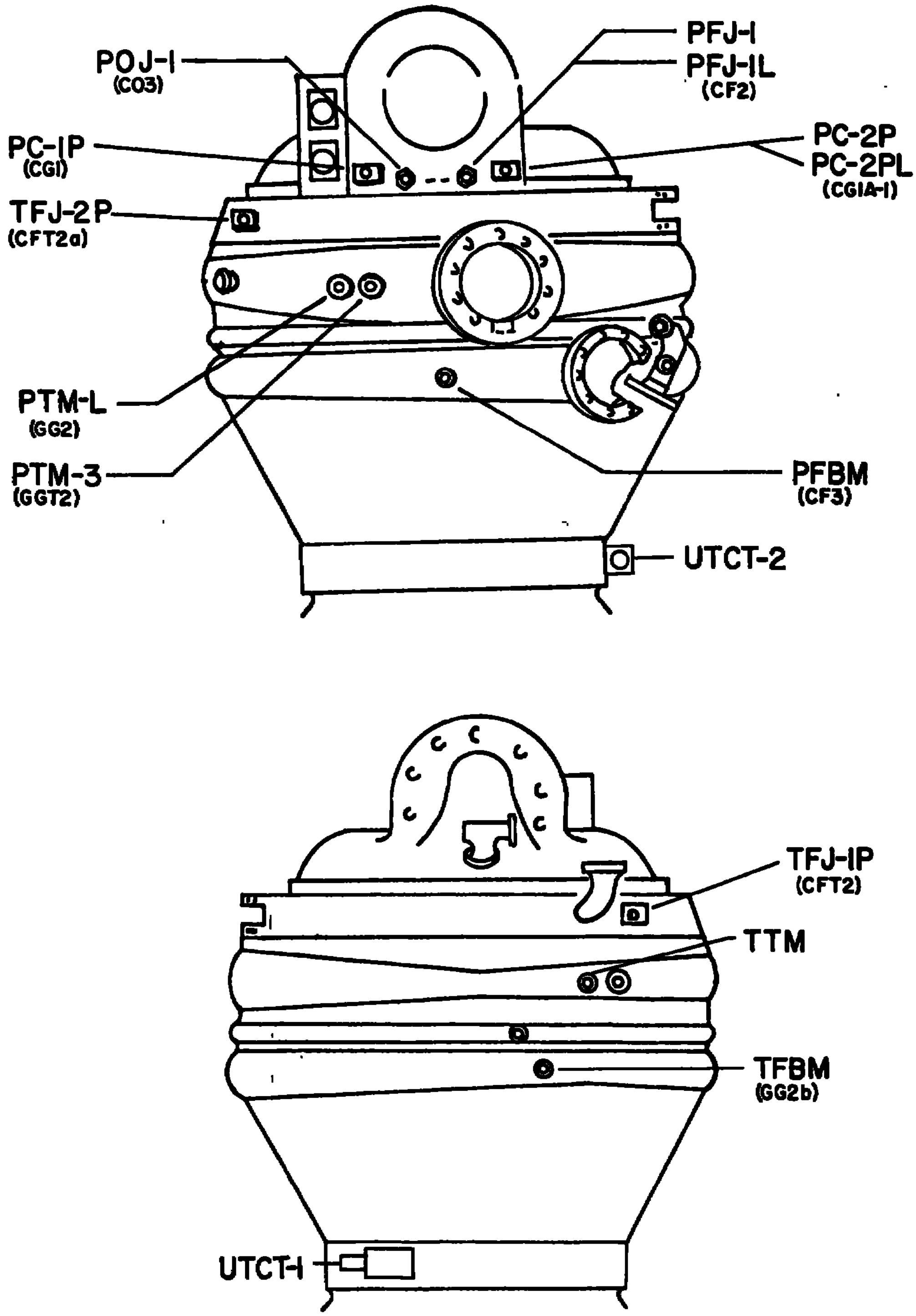
e. Oxidizer System Sensor Locations
Fig. III-1 Continued



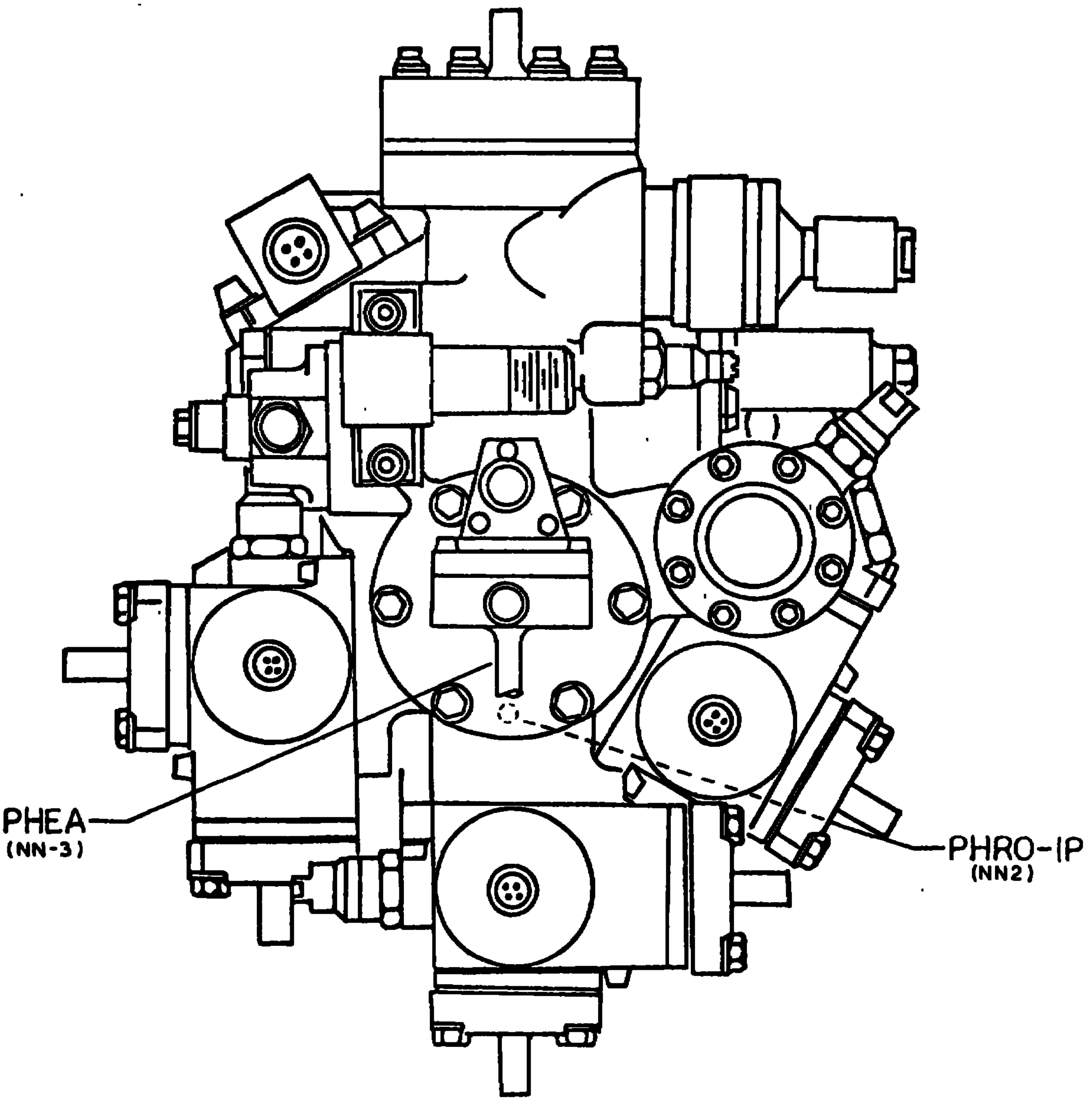
f. Turbine Exhaust System Sensor
Fig. III-1 Continued



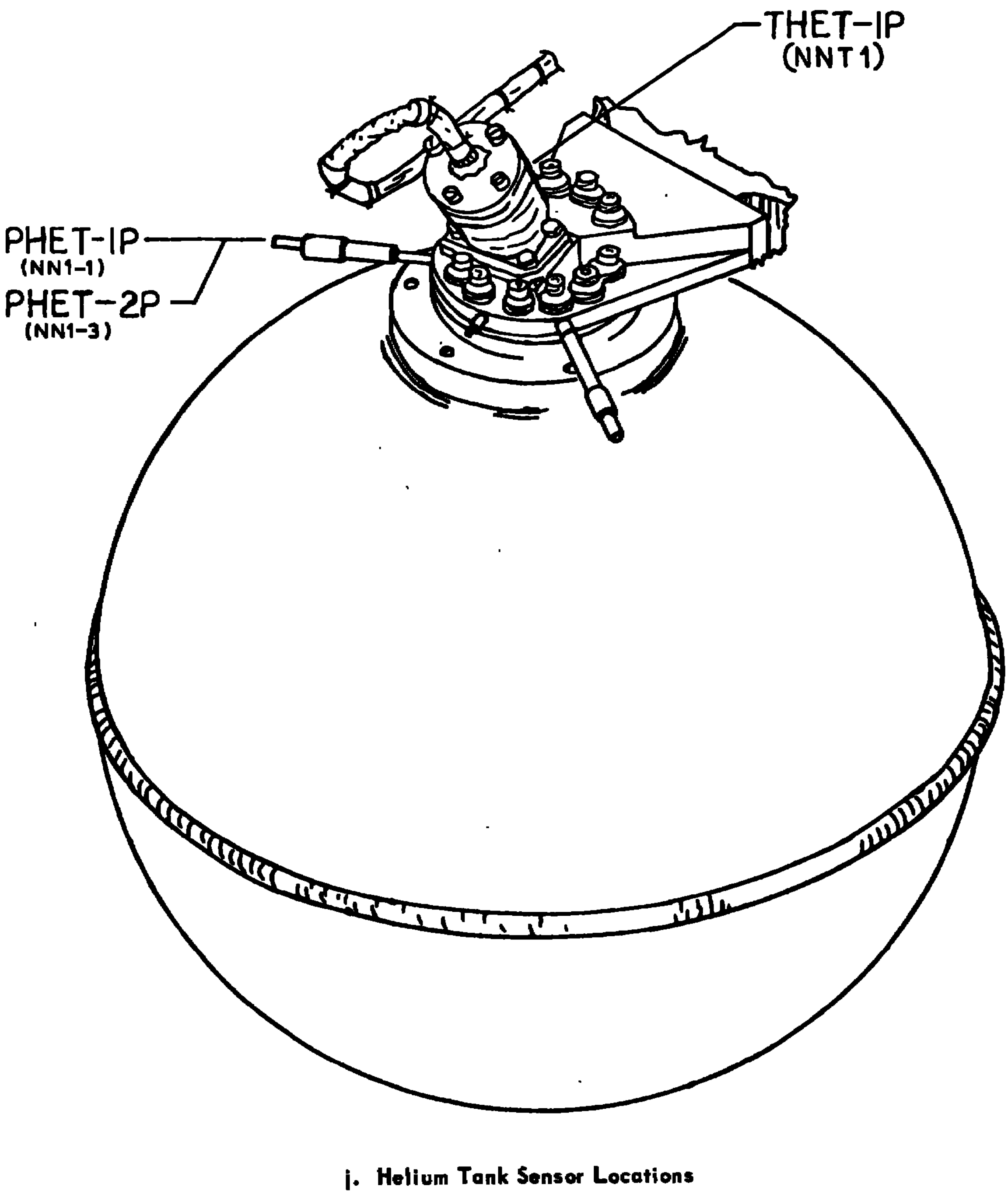
g. Thrust Chamber Injector Sensor Locations
Fig. III-1 Continued



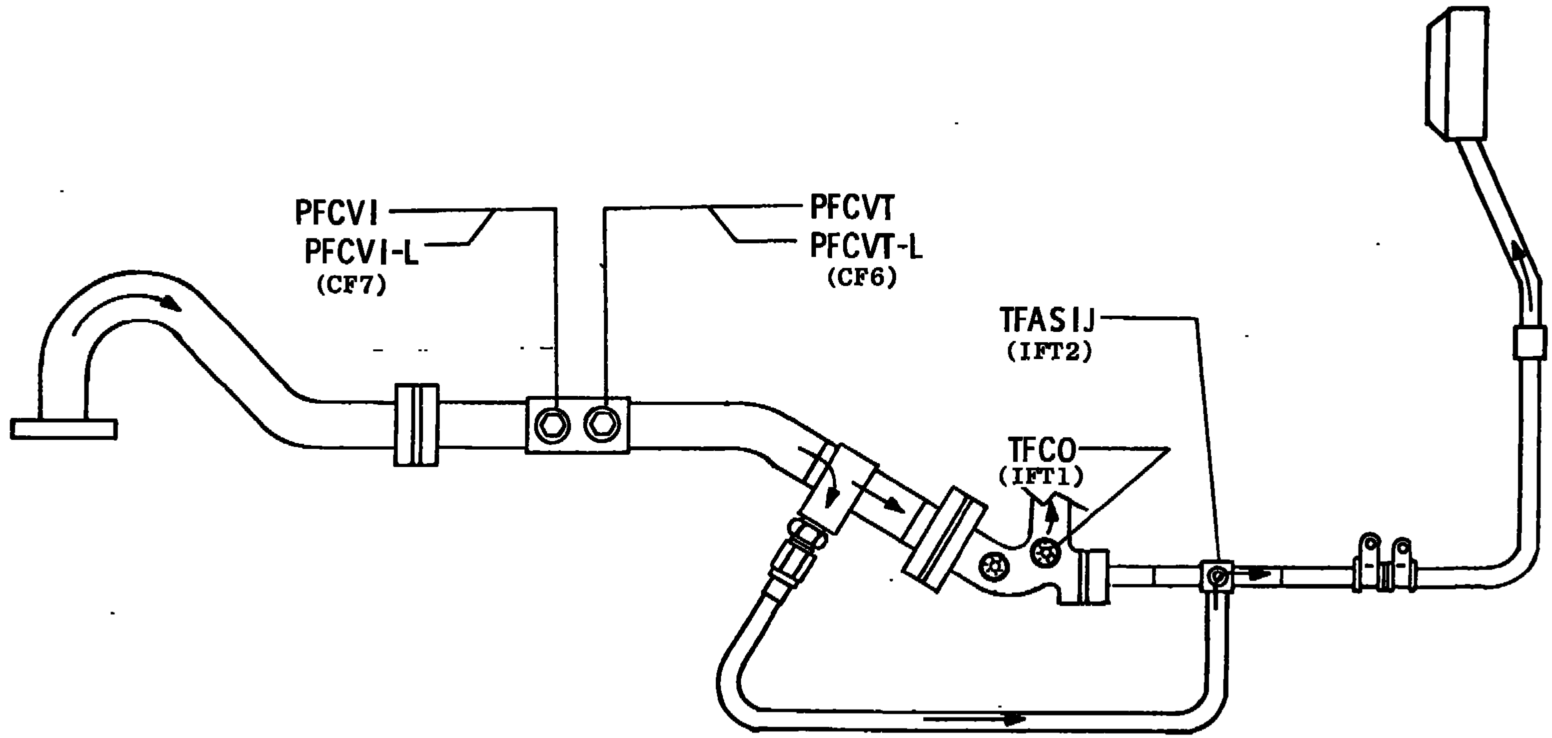
h. Thrust Chamber Sensor Locations
Fig. III-1 Continued



i. Pneumatic Control Package Sensor Locations
Fig. III-1 Continued

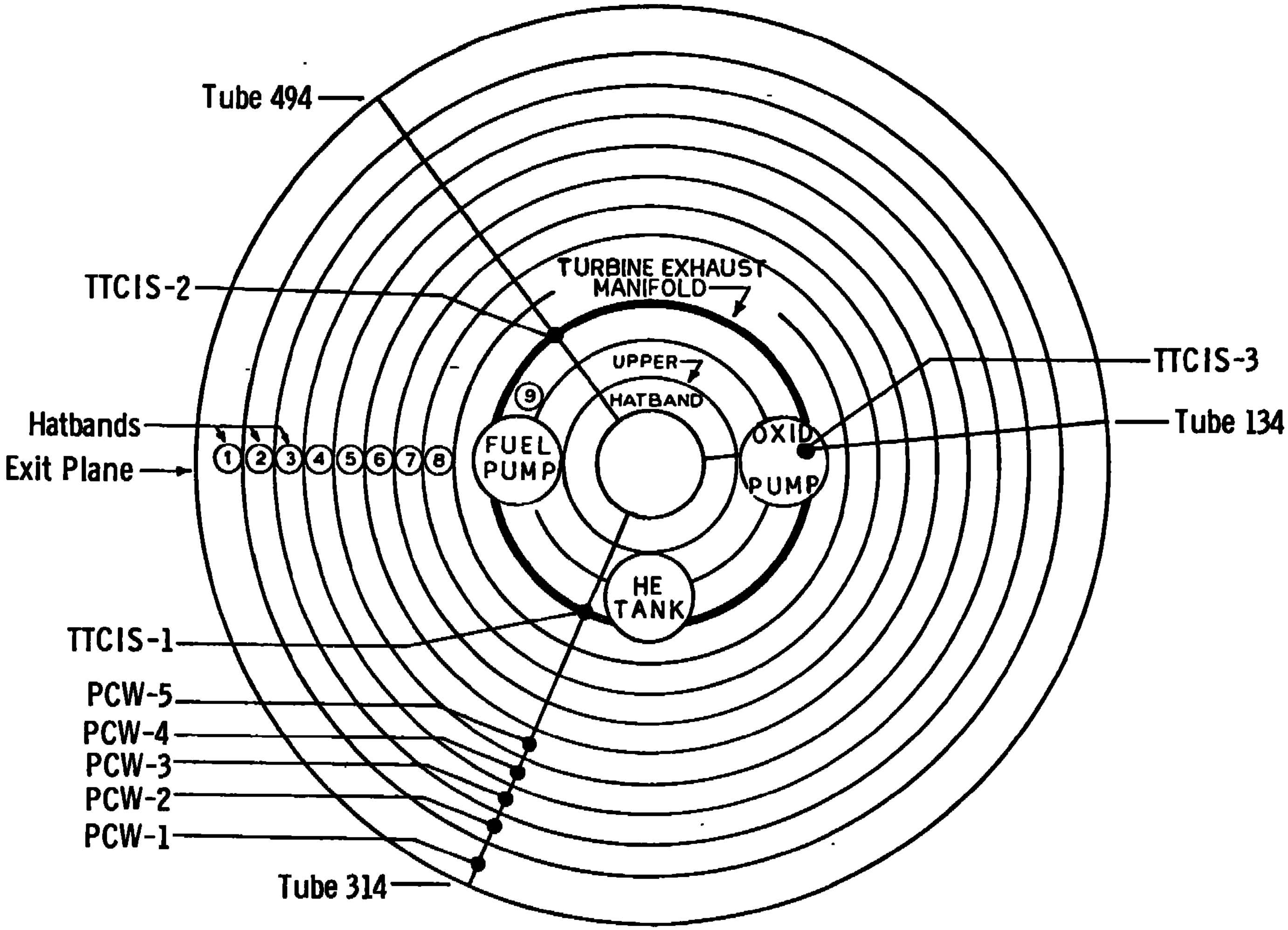


j. Helium Tank Sensor Locations
Fig. III-1 Continued



k. Film Coolant/Augmented Spark Igniter Fuel Supply Line Assembly Instrumentation

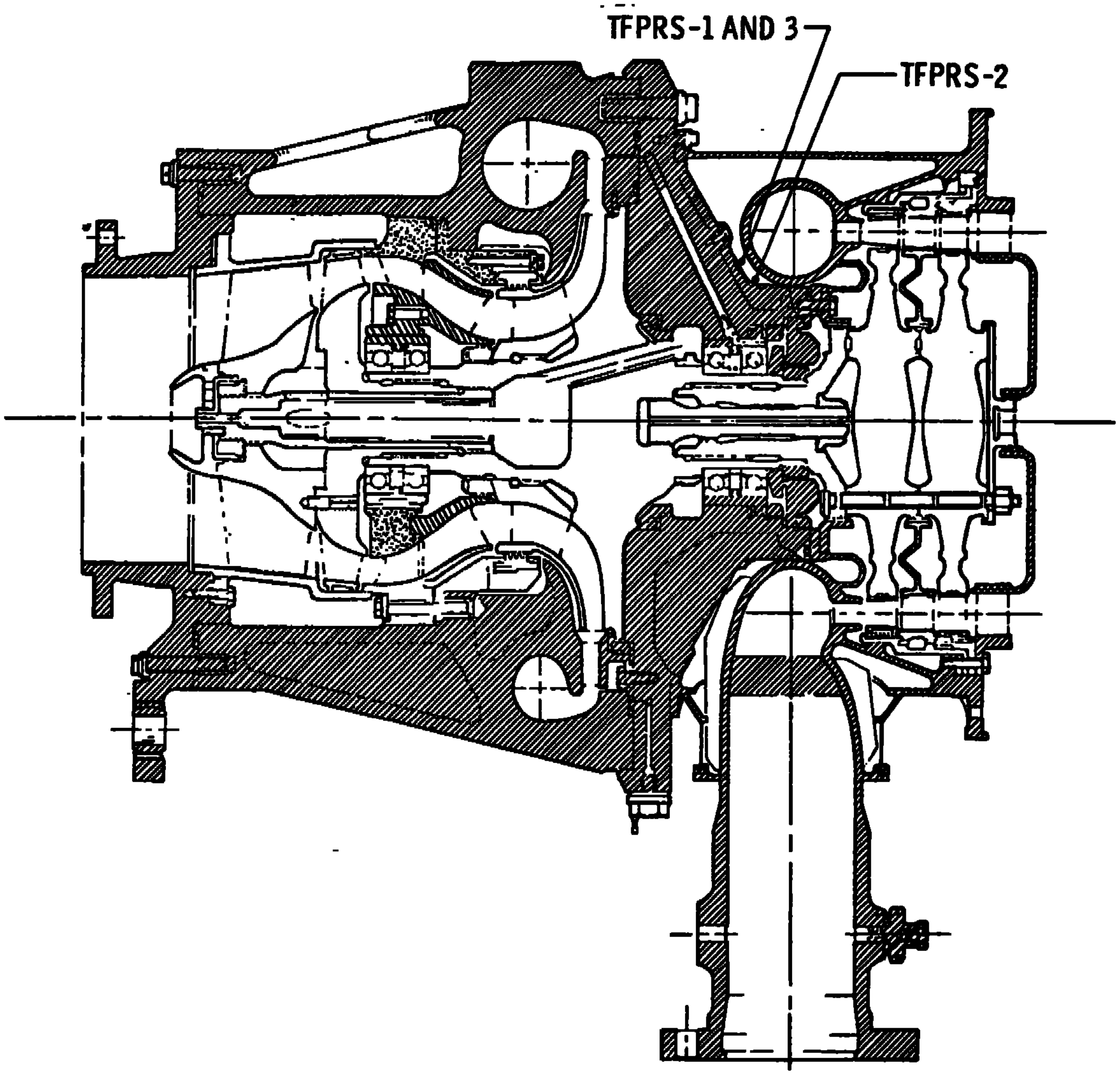
Fig. III-1 Continued



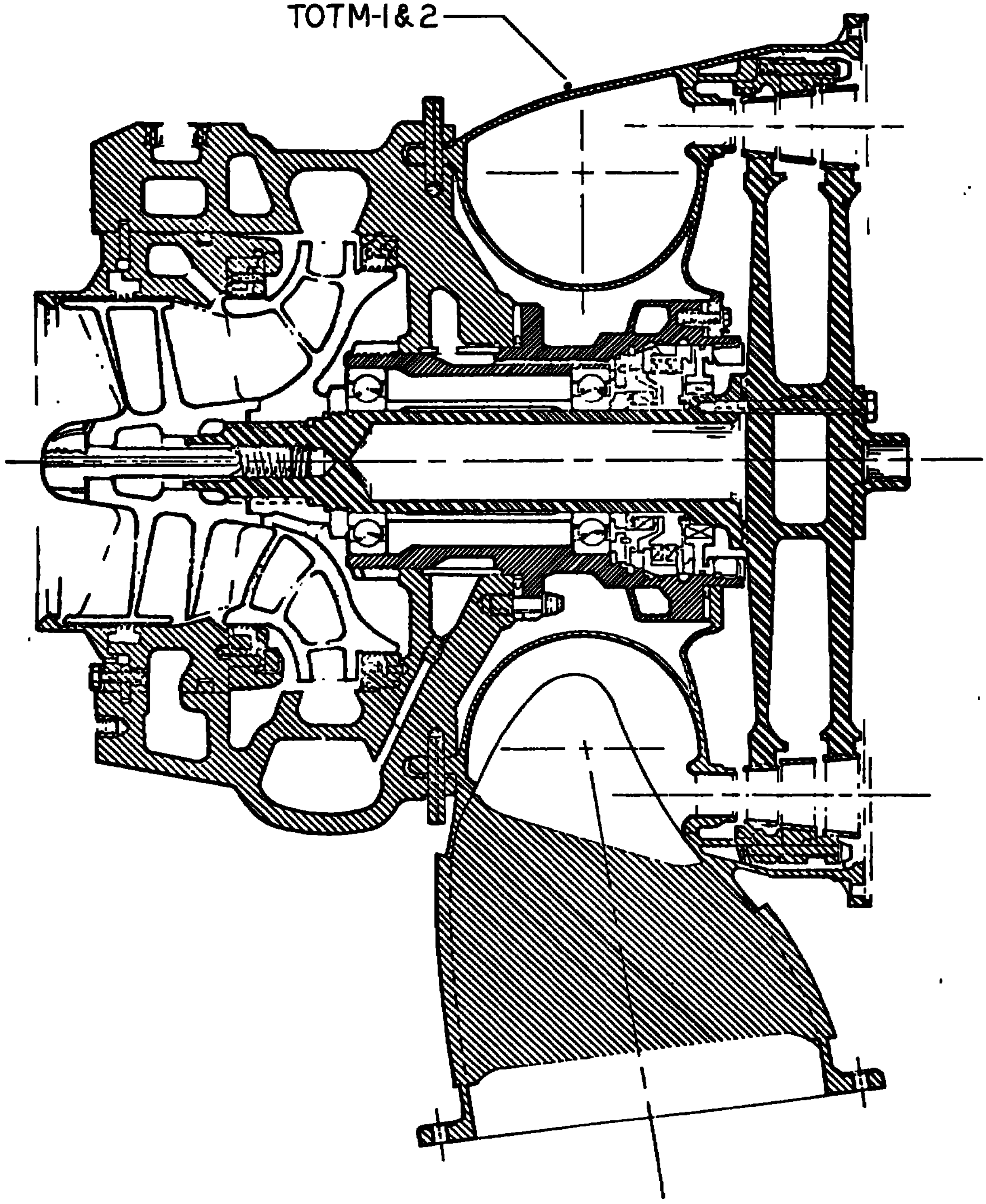
VIEW LOOKING DOWNSTREAM

I. Thrust Chamber Instrumentation

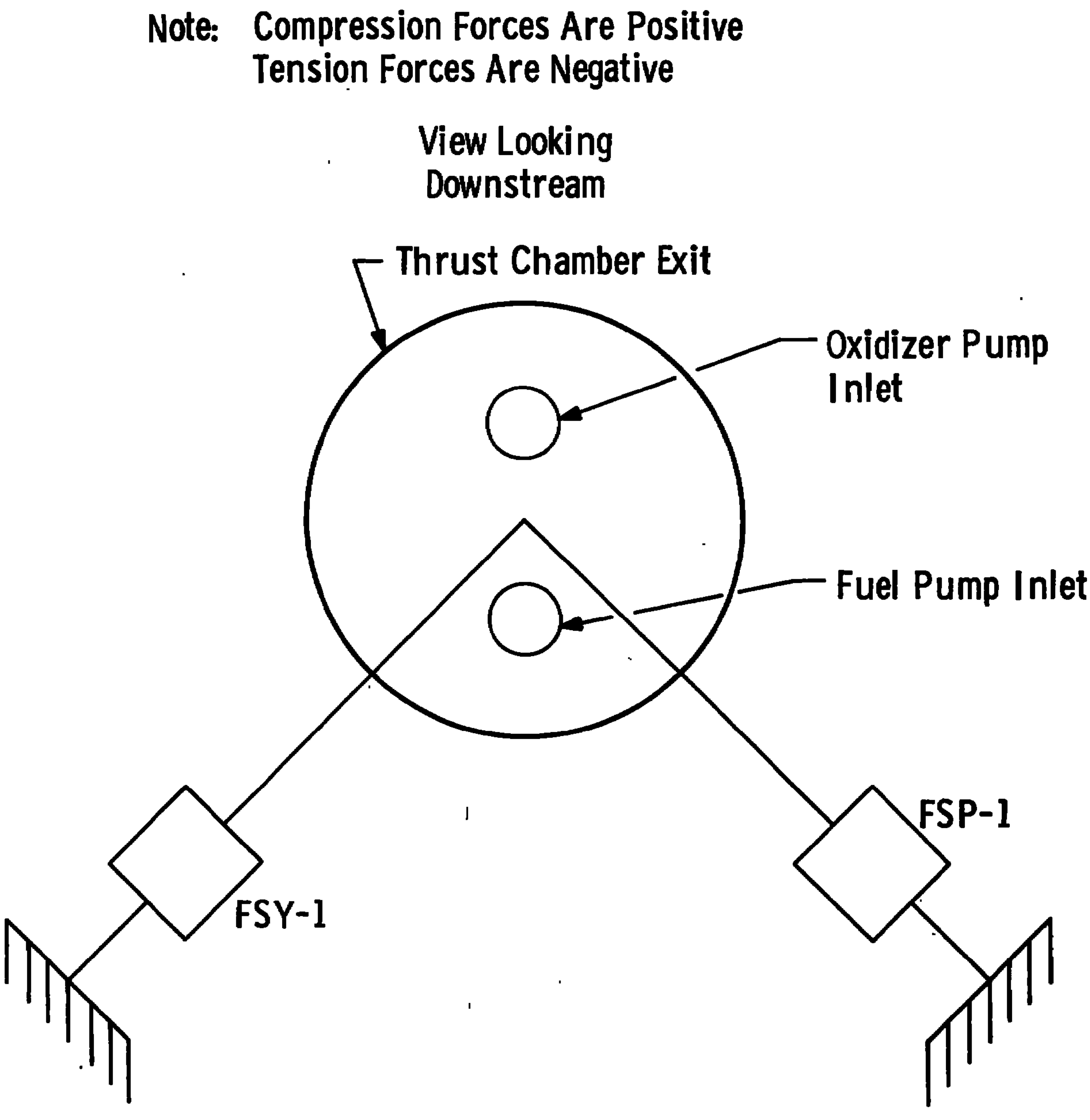
Fig. III-1 Continued



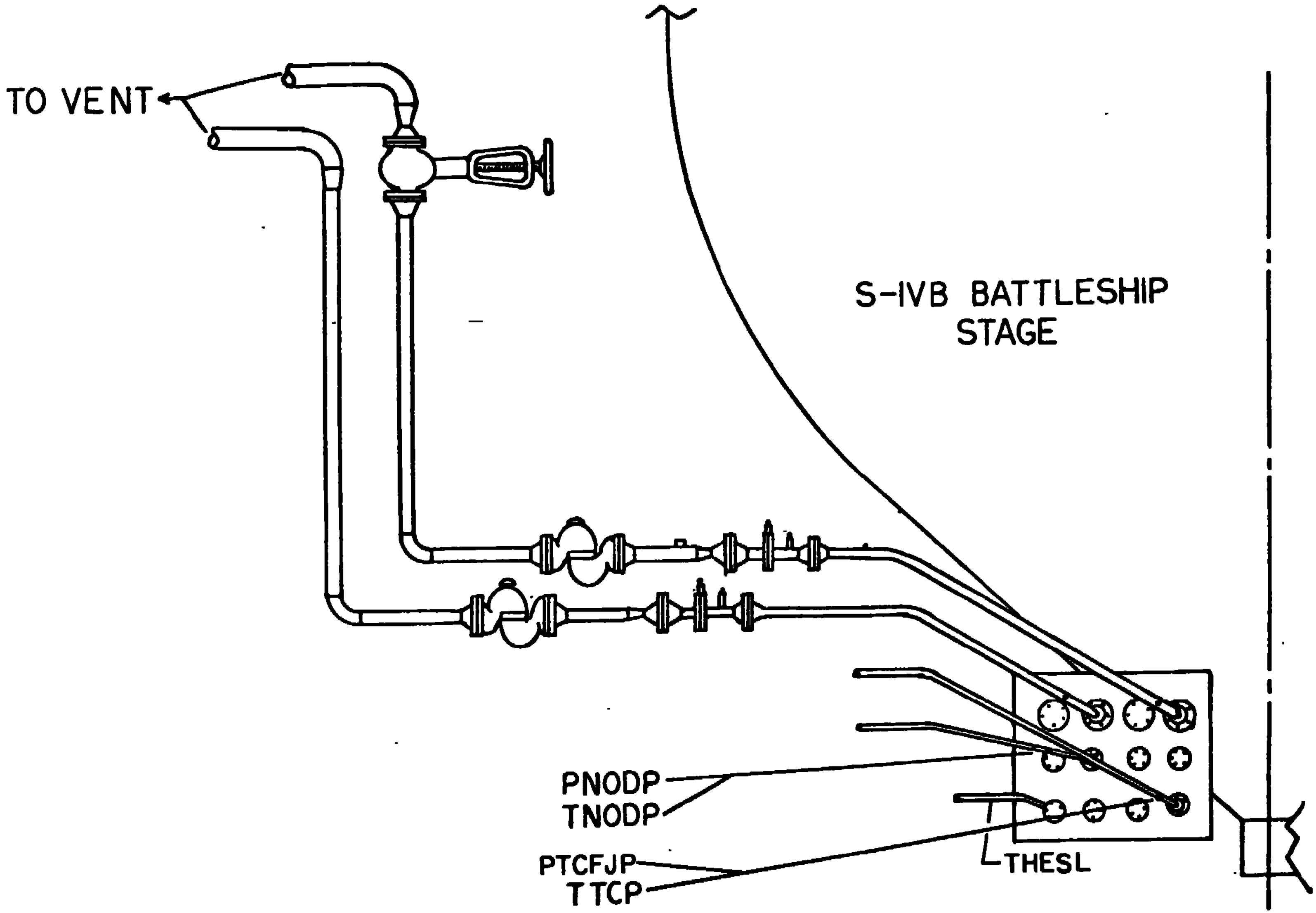
m. Fuel Turbine Sensor Locations
Fig. III-1 Continued



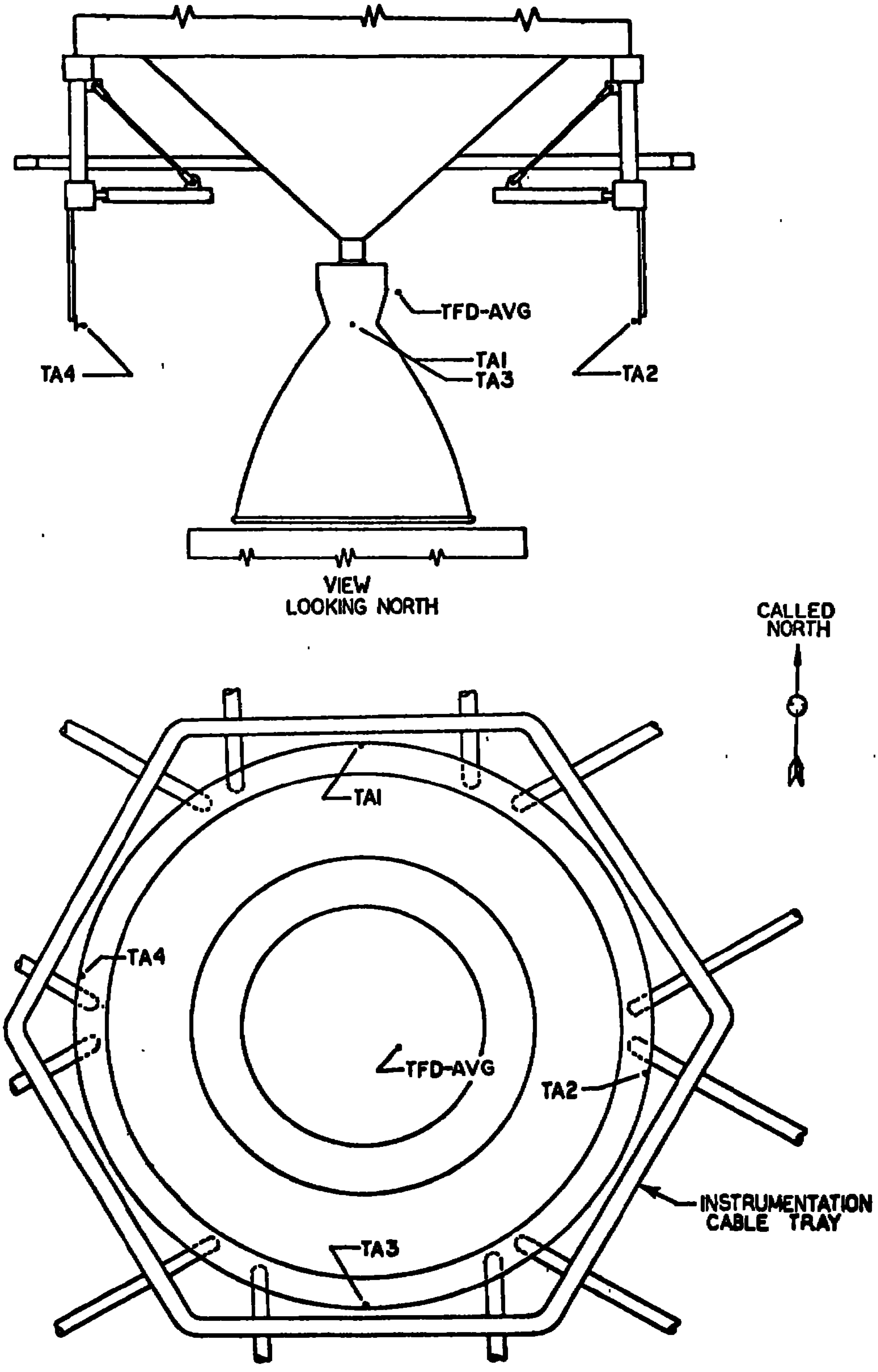
n. Oxidizer Turbine Sensor Locations
Fig. III-1 Continued



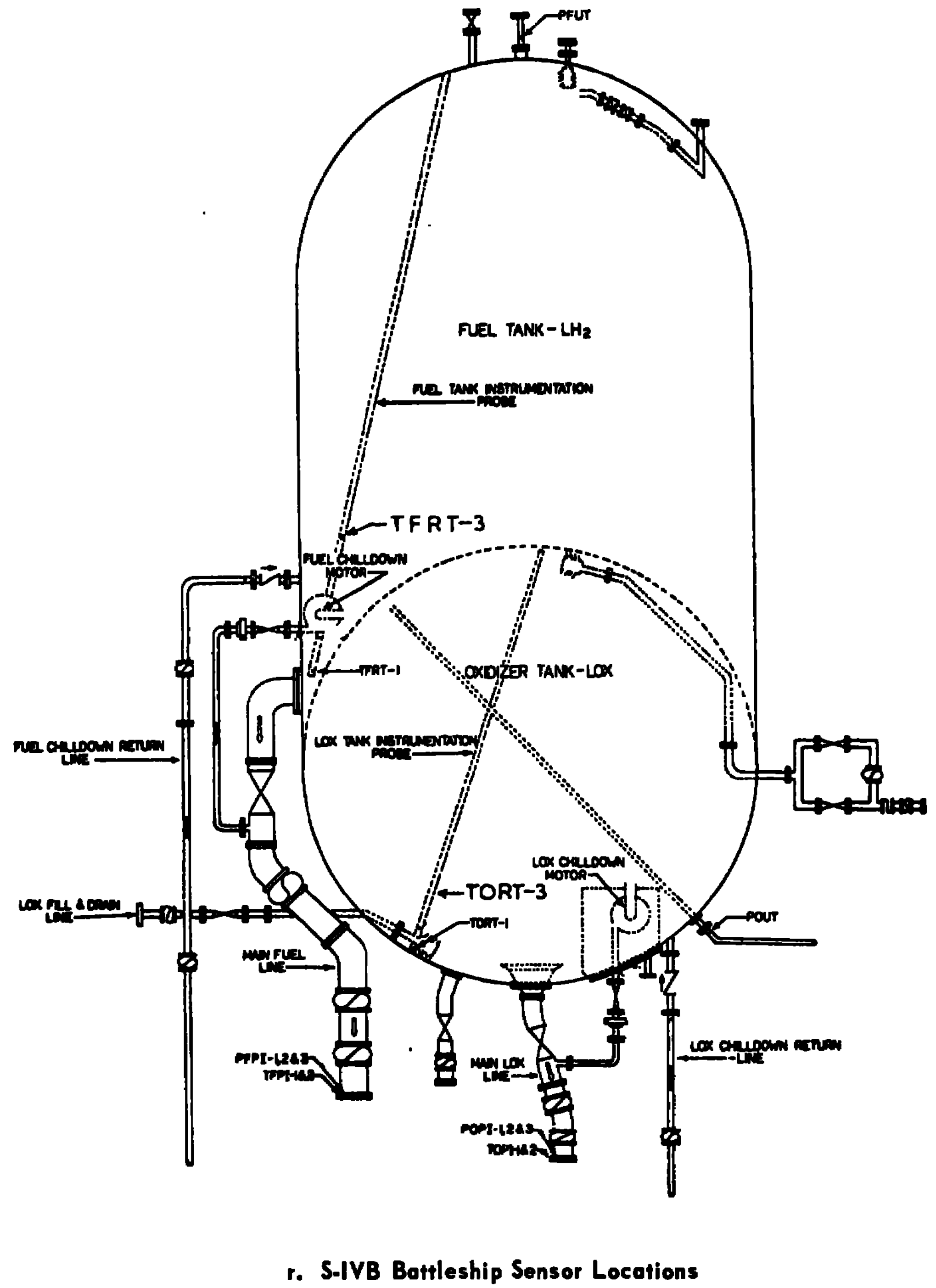
o. Side Load Forces Sensor Locations
Fig. III-1 Continued



p. Customer Connect Panel Sensor Locations
Fig. III-1 Continued



q. Test Cell Ambient Temperature Sensor Locations
Fig. III-1 Continued



r. S-IVB Battleship Sensor Locations
Fig. III-1 Concluded

APPENDIX IV
METHOD OF CALCULATIONS

NOMENCLATURE

A	Area, in.^{2}
CF	Coefficient of thrust
C*	Characteristic velocity, ft/sec
F	Thrust, lb_f
I	Impulse, sec
O	Oxidizer
P	Pressure, psia
W	Flow rate, lb_m/sec
ρ	Density, lb_m/ft^3

SUBSCRIPTS

a	Ambient
c	Chamber
e	Exit
eff	Efficiency
f	Fuel
fc	Film coolant
imc	Idle-mode compartment
inj	Injector
ns	Nozzle static
o	Oxidizer
sp	Specific
t	Total
vac	Vacuum

SUPERSCRIPTS

*	Throat

CALCULATIONS

I. IDLE-MODE PERFORMANCE

A. Theoretical (Ideal)

Calculations of theoretical rocket performance for chemical composition during an isentropic expansion were made by iterative computations using the method of calculations presented in Refs. 5 and 6. Computations were based on an enthalpy-entropy analysis, and program inputs were (1) reactants, (2) enthalpy of reactants, (3) stagnation pressure, (4) stagnation-to-static pressure ratio, and (5) nozzle exit area ratio. Enthalpy of reactants was obtained from Refs. 7 and 8 for hydrogen and oxygen, respectively.

B. Actual

Flow Rates

1. Total Propellant Flow Rate

$$W_t = W_f + W_o$$

2. Idle-Mode Compartment Fuel Flow Rate

$$(W_f)_{imc} = \frac{(A_f)_{imc}}{(A_f)_{inj}} W_f$$

3. Injector Flow Rate

$$(W_f)_{inj} = W_f - W_{fc}$$

Mixture Ratio

1. Total Propellant Mixture Ratio

$$O/F = \frac{W_o}{W_f}$$

2. Idle-Mode Compartment Mixture Ratio

$$O/F_{imc} = \frac{W_o}{(W_f)_{imc}}$$

Vacuum Thrust

$$F_{vac} = P_c A^* \, (CF_{vac}) \text{ ideal}$$

where

$$(CF_{vac}) \text{ ideal} = (CF) \text{ ideal} + \frac{A_e}{A^*} \frac{P_e}{P_c} \text{ ideal}$$

and

$$CF_{ideal} = F\left(\frac{A_e}{A^*},\ P_c,\ \frac{O}{F}\right) \text{ (from Refs. 5 and 6)}$$

Vacuum Specific Impulse

$$(I_{sp})_{vac} = \frac{F_{vac}}{W_t}$$

Characteristic Velocity

$$C^* = \frac{P_c A^* g}{W_t}$$

Characteristic Velocity Efficiency

$$C^*_{eff} = \frac{C^*}{C^* \text{ ideal}}$$

II. PROPELLANT FLOW RATES

Propellant flow rates are based on engine flowmeter constants supplied by the engine manufacturer: 5.50, 2.00, and 31.74 Hz per gal for the oxidizer, fuel and thrust chamber bypass flowmeters, respectively. Propellant properties for conversion of volumetric to weight flow were obtained from Refs. 8 and 9 for hydrogen and oxygen, respectively.

III. FUEL INJECTION DENSITY

Fuel injection density was estimated using the following equation supplied by the engine manufacturer:

$$\rho = \frac{[(W_f)_{inj}]^2}{(P_{inj} - P_c)}$$

where

$$K = 0.01106$$

IV. FUEL FILM COOLANT FLOW

Fuel film coolant flow was estimated by using the standard Venturi flow equation

$$W = C_D A\sqrt{2g(144)\,\Delta P \rho}$$

and

$$\left.\begin{aligned} C_D &= 0.97 \\ A &= 5.75 \times 10^{-3}\ \text{ft}^2 \end{aligned}\right\} \text{supplied by engine manufacturer}$$

thus,

$$W = 0.311\sqrt{\rho \Delta P}\ \ \text{lb}_m/\text{sec}$$

where

$$\Delta P = PFCVI - PFCVT$$
$$\rho = \rho\,(PFJ, TFJ)$$

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13. ABSTRACT

Five idle-mode firings of the Rocketdyne J-2S rocket engine (S/N J-112-1A) were conducted in Test Cell J-4 of the Large Rocket Facility on April 17 and 24, 1969. These firings were accomplished during test periods J4-1902-09 and J-1902-10 at pressure altitudes of approximately 100,000 ft at engine start. The objectives were: (1) to investigate engine idle-mode operating characteristics with a redesigned injector (oxidizer idle-mode compartment consisted of the injector posts in the tenth row from the center of the injector), (2) to determine fuel injection density for varying pump inlet pressures, and (3) to determine engine idle-mode performance. The lowest injection density was 0.055 lb_m/ft^3 with the thrust chamber bypass valve closed. Engine average characteristic velocity for this injector configuration was about 2.6 percent greater than that recorded during tests with the previous injector.

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
liquid propellant rocket engines						
altitude simulation						
performance						
injectors						

1 Rocket motors -- Performance

2 " " -- J-25

3 " " -- Double mode

4 " " -- Injectors

5 Fuel --

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